

Incorporating Non-structural BMPs into Integrated Watershed Models – Literature Review

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Ed Peacock
Environmental Resource Management Division

Abstract

The integration of both non-structural and structural BMPs into quantitative models of watershed hydrology and water quality has been a difficult task for those responsible for objectively optimizing expenditures on watershed management. The City of Austin hopes to achieve a better outcome in the next iteration of water quality planning through the Objective Zero (OZ) project. This effort aims to develop specific, measurable, achievable, relevant, and time-specific (SMART) water quality objectives through a process of distributed hydrologic and water quality modeling. The watershed modeling will be coupled with a thorough spatial representation of the development regulations, operating programs, and capital projects that make up the City's interventions for watershed management.

This literature review covers the non-structural best management practices sector to determine where quantitative methods have been developed which could be used to predict their effectiveness in pollutant removal and hydrologic restoration. Watershed education and outreach is examined in particular for available models of its effectiveness in reducing non-point source pollution and functional hydrologic alteration. The goal is to incorporate nonstructural BMPs like education and outreach alongside structural BMPs in a numerical model to determine where selective or proportional application of both would provide the most efficient control of water quality. In many cases such as the WPD Rain-Catcher Pilot Program (RCPP) or watershed stormwater control measure regulations and design criteria, a non-structural BMP may result in a structural component.

From the literature reviewed, little progress has been made on monitoring and modeling the quantitative impact of most non-structural controls since the initial National BMP database was completed in 2002. Non-structural BMPs have been deemed too complicated or confounding to monitor or model directly as methods to reduce pollutant load or hydrological impact. Given the human factors involved in many non-structural BMPs, it is natural that the first improvements needed would be those modeling pro-environmental behavior (PEB) in general and finding suitable external determinants of such behavior in socio-demographic data. When a non-structural BMP has a behavioral component, combining PEB theories with supporting community survey and census data may allow adequate prediction of behavioral change or adoption from City interventions that benefit water quality. However, the quantitative relationships between the current behaviors themselves and pollutant loading are tenuous in many cases. In previous efforts, this has been the major difficulty in modeling non-structural BMPs. If both the portion of the pollutant loading due to original behavior and loading change due to change in behaviors can be quantified through an agent-based model framework and PEB theory driven behavioral construct, a distributed hydrologic and water quality model may then be used to predict stream outcomes under any spatial logic of SCM placement, regulatory structure, and program strategy. Optimization of measurable endpoints of stream health relevant to stakeholders as constrained by cost and time would be the final step to objectively find the best mixture of watershed protection strategies across the City.

Introduction

Statement of the Problem

The City of Austin Watershed Protection Department (WPD) is currently grappling with a long-term planning question concerning the water quality objectives for local streams, rivers, springs, and aquifers. Like many organizations responsible for watershed protection and urban stream management, WPD lacks water quality objectives that are specific, measurable, achievable, relevant, and time-specific or SMART (Herrington 2017). Objectives based on current Maximum Extent Practical endpoints are too vague and subjective to guide informed decisions of focused effort for the department. Given its rapid growth and changing demographics, the City also needs new methods of resource allocation that are objective, yet responsive to the varied desires of the diverse community it serves. In WPD, water quality objectives are pursued through a combination of environmental and development regulations, programs, and capital projects. These interventions collectively are Best Management Practices (BMPs) with programs being primarily non-structural, capital projects being structural, and regulations pertaining to both. The funding allocation between development, promotion and enforcement of rules; management, growth and support of programs; and planning, design and construction of capital projects is made in a mostly ad hoc manner dictated often by extraneous influences. WPD has attempted in previous master-planning to make the process more objective; however, it has lacked having long-term water quality objectives that were SMART. A proposal in 2017 to undertake development of such objectives was the basis of need for a method to compare the benefits of these very different water quality interventions (regulations, programs, projects) on a level playing field using spatially distributed and quantifiable metrics that are acceptable by social and natural scientists as well as water quality engineers and importantly - City management, stakeholder groups, City Council and citizens.

One of these interventions that the City excels at is that of watershed education and outreach. The use of environmental education and outreach to produce pro-environmental behavior has been studied in general and in theory in the social sciences and this research is beginning to be used in application to non-structural water quality controls in estimating quantitatively the pollutant reduction benefit they provide to a municipality (HDR 2014, 2016). A WPD project in the Waller Creek watershed, the Rain Catcher Pilot Project (RCPP), is underway to determine effectiveness of outreach behavioral “nudges” in increasing participation in a residential Green Stormwater Infrastructure (GSI) incentive program. In addition, WPD Education and Outreach is contracting for a Market Study of the City to determine spatial differences in projected effectiveness of its programs.

As part of the Objective Zero (OZ) project, a literature review is needed to determine the best methods available to quantify the impact of WPD non-structural water quality controls for inclusion into a watershed modeling framework. A particular need is synthesis of literature on the effectiveness of watershed education and outreach programs on citizen behaviors that result in pollutant load reduction and stream hydrograph modification that can be spatially located along with other BMPs, both structural and non-structural, in an integrated watershed planning model.

Purpose

The research question needs to be answered primarily because resource allocation decisions between these interventions cannot be made on an objective basis or on an equity basis without common quantitative objectives, quantitative intervention performance measures, and an internally consistent model that includes a physical watershed basis, social theory construct, and local calibration data. In a wider view, non-structural BMPs must be added into this planning model because urban runoff as a non-point source of pollution is one of the main drivers for water quality degradation of natural waterbodies

and the availability of strategically placed undeveloped property in the urban landscape does not accommodate a strictly structural approach to water quality control. Moreover, recent ecological research has suggested that human behavior has influenced the course of biophysical processes in the environment as compared with natural events. Thus, human behavior should be considered as components of the ecosystem to be adjusted. Alberti et al (2003) state that “humans are changing the ecological stage on which the evolutionary play is performed. To understand the new evolutionary play, ecological scholars must build a new stage with humans as a central plank.”

Therefore, non-structural controls will remain a necessary part of the BMP toolbox for municipalities and their benefits should be considered objectively along with structural controls. We hope to use any methods identified for watershed education to develop models for other non-structural BMPs until the OZ watershed models that were envisioned are complete for use in long term planning (Herrington 2017). Naturally, the OZ models will be adapted over time as new data may be obtained and the priorities for Austin citizens may change.

Research Question

This literature review is aimed at both the specific effectiveness quantification of behavioral interventions in watershed protection such as education and outreach programs and the more general quantification of non-structural watershed BMPs in water quality modeling. First, how can the benefits of focused WPD watershed environmental education and outreach programs be quantified for comparison and combination with the benefits of structural BMPs in an integrated watershed planning model? Secondly, how can education and outreach and the rest of the suite of non-structural BMPs used in Austin be represented quantitatively in watershed models being developed for the OZ project?

Methods

Literature pertaining to the research question was found across several disciplines. Much of the theory behind what motivates pro-social and pro-environmental behavior is found in environmental psychology, organizational psychology, and social psychology (Bamberg and Moser 2007; Aizen, 1991). Research specific to environmental education and outreach as motivation for pro-environmental behavior was found in environmental education journals as well as the psychology specialties just mentioned (Hines, Hungerford and Tomera 1986; Obaldston and Schott 2012). Socioeconomic and demographic determinants of pro-environmental behaviors and the interaction of environmental equity and justice variables were found in social work, environmental management and urban planning research areas (Maeda et al., 2018; Brehm, Pasko, and Eisenhauer 2013). Finally, the use of these variables in municipal watershed planning and modeling was found both in the environmental and watershed engineering research as well as the project reports applying this varied research to master-planning, drainage utility management, and watershed protection/implementation plans for compliance with federally or state-mandated stormwater discharge permitting (CASQA 2015; USEPA 2007, 2017; Herrington 2017; HDR 2016).

Although there was a general acknowledgment early-on that non-structural BMPs like watershed education and outreach were necessary components of municipal watershed protection, little agreement or guidance is provided by US regulators or planning agencies as to how results of such interventions should be quantified (ASCE and EPA 2002; HDR 2016). No specific guidance on quantitative estimation of behaviorally dependent pollutant loadings or their reductions through non-structural interventions is provided in the Total Maximum Daily Load (TMDL) or Waste Load Allocation (WLA) programs at EPA or TCEQ (USEPA 1997, 2007, 2019 Sept 30 Chris Loft TCEQ personal communication). However, there is an abundance of information pertaining to how to conduct effectiveness evaluation of all approaches to

stormwater management in the California Stormwater Quality Association (CASQA) BMP literature (CASQA 2003, 2013, 2015). Also, one of the first textbooks devoted to pro-environmental behavior and its application to life-cycle assessment of actual environmental burdens was published in 2015 (Kurusu 2015). In addition, literature from the Behavioral Insight Team (BIT) or “Nudge Unit” created by the UK government documents behavior interventions in the UK and US designed to improve public services. The BIT has focused work on municipalities and how they can use behavioral science to improve public programs and policies. Their work includes qualitative methods to predict social behavior using a segmentation model based on grouping of determinants and methods to influence behavior through “nudges” that among other things may increase the “take-up of services” similar to adoption of non-structural BMPs through incentive programs similar to the RCPP (BIT 2016, 2017, 2018).

Although this literature review does not meet PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) standards or any similar protocol for systematic reviews, an attempt was made to be thorough in researching each area (Liberati et al 2009, Rubio-Aparicio 2018). Procedures from these standard organizations were reviewed and applied selectively when possible. Formal use of such standards may be warranted if recalculation of previous meta-analyses is needed in creating a new structural equation model for the OZ project. Databases used included PubMed, Science-Direct, JStor, Web of Science, and Google Scholar. Journal and publication indexes used included the those associated with American Society of Civil Engineers (ASCE), Water Environment Federation (WEF), Association of Agricultural and Biological Engineers (ASABE), Social Sciences Research Network (SSRN), PsychINFO and the Journal of Environmental Psychology under the International Association of Applied Psychology (IAAP). Keyword and phrase searches included non-point source pollution, pro-environmental behavior, stormwater, water quality, hydrologic modification, value norms behavior model, norm activation model, theory of planned behavior model, agent-based models, causal models, structural equation modeling, path analysis, counterfactuals, best management practices, stormwater control measures, non-structural BMPs, environmental education, watershed education, environmental outreach, watershed models, and most importantly various combinations thereof.

A great deal of time was spent digging through grey literature such as watershed planning documents, engineering project reports, state/regional/local program descriptions, and model users guides when non-structural BMPs were mentioned in order to determine exactly how their effectiveness was calculated. This search was based on leads in articles, agency guidance, or public facing webpages of project results. In most cases, only a fraction of the range of non-structural BMPs commonly employed or employed in Austin were addressed. The programs and projects that turned up the best attempts to model non-structural control effectiveness came from Portland, San Diego, Delaware, and multiple participants in the Chesapeake Bay project. There may be more projects that provide key methodology development, but the access to these project reports is not universally available, so this avenue could not have been pursued exhaustively.

Results and Discussion

Classification of non-structural BMPs

Categorization of non-structural BMPs varies widely across the models and studies evaluated. Some studies characterize all stormwater BMPs into those with action on a point (basin and outfall), linear (buffers, riparian, roadway), or areal (site, soil, impervious cover) basis. Other entities separate source control BMPs from others that act on collected stormwater. Most non-structural BMPs are said to be source control and areal in action (Shoemaker et al. 2009). Distributed residential structural BMPs were in many programs also be considered source control and if incorporated into a voluntary incentivized municipal program for private properties, they can also be considered to be the end result of a non-

structural behavioral BMP. In fact, some researchers classify rain gardens, vegetated swales, disconnection of impervious services, and reuse of rainwater as non-structural BMPs (Pazwash 2011).

Some agencies and organizations have a narrower definition of what is “non-structural”. The State of Pennsylvania considered the following BMPs in their statewide manual to be non-structural (PDEP 2006):

1. Protect Sensitive and Special Value Resources
 - a. Protect Sensitive/Special Value Features
 - b. Protect/Conserve/Enhance Riparian Areas
 - c. Protect/Utilize Natural Flow Pathways in Overall Stormwater Planning and Design
2. Cluster and Concentrate
 - a. Cluster Uses at Each Site; Build on the Smallest Area Possible
 - b. Concentrate Uses Area wide through Smart Growth Practices
3. Minimize Disturbance and Minimize Maintenance
 - a. Minimize Total Disturbed Area – Grading
 - b. Minimize Soil Compaction in Disturbed Areas
 - c. Re-Vegetate and Re-Forest Disturbed Areas, Using Native Species
4. Reduce Impervious Cover
 - a. Reduce Street Imperviousness
 - b. Reduce Parking Imperviousness
5. Disconnect/Distribute/Decentralize
 - a. Rooftop Disconnection
 - b. Disconnection from Storm Sewers
6. Source Control
 - a. Street-sweeping

The categorization above focuses on the desired function and mode of action of the non-structural BMP on the ground as commonly enforced through regulations on site planning and development practices with the exception of street sweeping, a typical municipal maintenance program. It neglects to include any voluntary behavioral BMPs such as education and outreach programs and incentive based programs for voluntary individual and group actions to improve stormwater quality and hydrologic function. The effectiveness of the list of BMPs above would still be difficult to quantify and would not be straightforward to model without being able to automate calculation of pollutant loadings for multiple development alternatives on a lot by lot basis. Also, extensive geographic information on developable land, redevelopment probabilities, emerging development projects, development permits in process, riparian areas, soil condition, critical environmental features, and roadway/parking projections would be needed uniformly over the modelled watershed area.

In the USEPA white paper on the use of BMPs in urban watersheds, another categorization of non-structural BMPs was provided:

Public Education

Planning and Management of Developing Areas

- Better Site Design

- Vegetation Control

- Reduction/Disconnection of Impervious Areas

- Green Roofs

- Low-Impact Development (LID)

Materials Management

- Alternative Product Substitution

- Housekeeping Practices
- Street/Storm Drain Maintenance
 - Street Cleaning
 - Catchbasin Cleaning
 - Roadway and Bridge Maintenance
 - Storm Drain Flushing
 - BMP Maintenance
 - Storm Channel and Creek Maintenance
 - Stormwater “Hotspots”
- Spill Prevention and Cleanup
 - Above Ground Tank Spill Control
 - Vehicle Spill Control
- Illegal Dumping Controls
 - Storm Drain Stenciling
 - Household Hazardous Waste Collection
 - Used Oil Recycling
- Illicit Connection Controls
 - Illicit Connection - Prevention, Detection and Removal
 - Failing Septic Systems and Sanitary Sewer Overflows
- Stormwater Reuse

The list above includes some behavior-based BMPs like public education, product substitution, housekeeping practices, spill prevention, and used oil recycling. It also includes BMPs that are not commonly considered to address stormwater problems such bridge and roadway maintenance, above ground tank and vehicle spill control, failing septic system and sanitary sewer system overflow remediation. USEPA also explained that significant blurring of the definition of non-structural BMPs is found in Low Impact Development and Green Infrastructure where structures may be distributed to individual lots and could be considered source controls (USEPA 2017).

Classification of non-structural BMPs in a literature review and bmp manual produced for Western Australia included the following five categories (DESRT 2005; Taylor and Wong 2002a):

1. Town planning controls - such as the use of town planning instruments to promote or require water sensitive urban design features in new developments. This would correspond to Imagine Austin, and neighborhood plans locally.
2. Strategic planning and institutional controls - such as the use of strategic, regional or citywide urban stormwater management plans and enforced regulatory adherence to these plans. The Watershed Protection Masterplan 2015/2016 Update could be considered in this category as well as the regulations implementing it (WPD 2015). The Barton Springs Zone Regional Water Quality Protection Plan could also be considered under this category although it does not have a single regulatory authority or funding source behind it (Naismith 2005).
3. Pollution prevention procedures - such as maintenance practices, operational procedures and staff training at government, commercial and industrial sites to minimize the risk of stormwater pollution. City departmental SOPs and some training provided by the ERM Education and Outreach section of WPD would qualify.

4. Education and participation programs - such as training programs and involving the community in the development and implementation of stormwater management plans. The bulk of programs designed by ERM Education and Outreach would fit here.
5. Regulatory controls - such as enforcement of local ordinances to improve erosion and sediment control on building sites, the use of environmental permits to help manage premises likely to contaminate stormwater or groundwater, and programs to minimize illicit discharges to stormwater management systems. Regulations in the Land Development Code as well as guidance in the Environmental Criteria Manual and Drainage Criteria Manual would contribute to this category of non-structural controls locally.

The USEPA Phase 2 rules for MS4 permitting requires six elements that, when implemented together, are expected to reduce pollutants discharged into receiving waterbodies to the Maximum Extent Practicable (MEP). These six program elements, or Minimum Control Measures (MCM), are:

- Public Education and Outreach on Storm Water Impacts;
- Public Involvement/Participation;
- Illicit Discharge Detection and Elimination;
- Construction Site Runoff Control;
- Post-Construction Storm Water Management in New Development and Redevelopment;
- Pollution Prevention/Good Housekeeping for Municipal Operations.

Although these MCM include construction and post-construction stormwater management which are more structural in nature, the majority are essentially programmatic and regulatory non-structural source control BMPs (USEPA 2019). Regardless, no assistance with how to calculate load reductions or hydrologic improvements could be found in guidance or permitting literature for implementing these MCM (USEPA 2019). The USEPA did manage to go as far as to say that a method for calculation of benefits and confirmatory monitoring were needed (USEPA 2017).

The suite of non-structural BMPs of most concern are those that will be applied by WPD and evaluated in the OZ project. It is difficult to provide an exhaustive list because new strategies are being investigated continuously by WPD, programmatic changes eliminate some strategies, and regulatory changes modify which BMPs are promoted for implementation. The list of non-structural BMPs for Austin may differ from municipalities in other states who may have more or less freedom to enforce land development controls and other regulations than those in Texas. Other municipalities also may not have as many voting citizens with a high degree of environmental awareness and commitment as Austin has been known for historically.

Also, the Land Development Code rewrite is still under consideration and may be modified before implementation. Some BMPs will be easier or more difficult to implement as a result of the rewrite and following any associated changes made to the Environmental and Drainage Criteria Manuals. Compared to the non-structural BMPs implemented by other municipalities, the list of Austin's programs, regulations, and project types is fairly comprehensive. The funding allocated to WPD through the Drainage Utility Fund as an Enterprise Department also enables it to select and implement a wide number of progressive non-structural BMPs that might not be approved elsewhere. Finally, other municipalities may not have federally endangered aquatic species in karst habitats that require more attention to contributing watershed BMPs.

The WPD Masterplan Update for 2015/2016 included a lengthy inventory of potential solutions for each of the department's missions of flood control, erosion control, and water quality protection/improvement

(WPD 2015). Over the three missions there were 55 capital solution types, 38 programmatic solution types, and 58 regulatory solution types. The masterplan also referenced 26 new solutions incorporated into the projects, programs, and regulations of the WPD (COA 2016). A separate integrated mission category captured additional solutions. Appendix A provides a summary of these BMPs and a categorization structure to help characterize groups that might have similar methods of pollutant loading quantification.

The goal of categorizing non-structural BMPs is to determine groups that may have similar mechanisms of implementation and interactions with human behavior requiring the same assumptions, equations, parameters, and calibration to be supportable. However, the literature still has no uniformity whatsoever in what is considered a non-structural BMP or which non-structural BMPs are significant enough in terms of load reduction to bother quantifying individually. In the OZ project, the goal would be to have every expenditure of WPD funding not associated with a City funded structural BMP modeled as funding a non-structural BMP. However, quantifying the benefits of some WPD programs such as water quality monitoring and data analysis in terms of direct change in behavior or direct links to pollutant load reductions may be difficult. At a minimum, these data collection and synthesis functions provide scientific information to the education and outreach function and contribute to public awareness of watershed problems, priorities, and methods of solution. Such awareness is one of the significant determinants of environmental behavior change in many models (Latif et al 2013, Bamberg and Moser 2007). In addition, many of the functions of WPD technical programs in data analysis and planning are to improve the targeting and execution of public capital projects and optimize the impact of regulations on private development capital projects to reduce cost and improve benefits to the environment.

Appendix A includes the author's attempts to categorize the masterplan solutions into those purely structural, non-structural and those with characteristics of both. As a generalization, those solutions (BMPs) that are not City-funded capital expenditures on "bricks and mortar" would have non-structural components. Even regulatory solutions require compliance, which is considered a pro-environmental behavior in many studies (Grassmick et al. 1991, Lloyd et al. 2001, Barnes et al. 2013, OECD 2017, Okumah et al. 2018). Compliance has its own profile of social and personal norms. In addition, design criteria and selection of structural BMPs to use on private development projects also have a component of design professional decision-making which could be considered pro-environmental behavior of a target group within the population. Nudges such as subsidized training in green stormwater infrastructure of private design professionals by a City program could be considered a non-structural BMP. Therefore, any of the solutions categorized as regulatory or programmatic could be considered to have a component that is non-structural whether or not they result in a privately funded "bricks and mortar" solution on the ground. As the OZ modeling progresses, this proposed categorization may be tested and modified as equations for quantifying each BMP are added to the distributed watershed hydrology and water quality model.

Watershed Education and Outreach as Quantifiable Stormwater BMPs

There are multiple reasons for attempting to quantify the benefits of non-structural BMPs including education (Taylor and Fletcher 2007):

- Many are much less expensive to implement than structural BMPs, occasionally revenue neutral to management agencies
- Some, like city-wide education and outreach can cover broad geographic areas compared to structural alternatives.
- Most can be used in a retrofit, redevelopment, or new development context such as high-density urban area where structural measures would be difficult or disproportionately expensive.

- Some measures such as education and outreach may be targeted at specific pollutants of concern such as pathogens, nutrients, or pesticides/herbicides.
- Many provide an opportunity for community involvement, which can help build human and social capital
- Many can be quickly modified to respond to new circumstances or terminated when conditions have changed in contrast to structural measures which can be at risk of being “stranded assets”.
- Some measures, especially citywide education and outreach serve a role in building political support and a mandate for funding more advanced stormwater management initiatives with state and federal participation.

Given the categorization in Appendix A, there are several common factors that go into quantifying education and outreach as pollutant load reduction for modeling purposes. First, there are a number of outreach non-structural BMPs that lead to structural BMPs that have already been studied sufficiently so that their effectiveness can be calculated in watershed models. Some of these have both a surface water and groundwater quality impact whereas others have one or the other. Some influence surface and/or groundwater hydrology in a manner that has already been studied sufficiently to model. The bulk of these BMPs incorporate some form of targeted detention or infiltration. The mechanisms of their individual effectiveness and the pollutant parameters that they act on are known and are physically based. The remaining uncertainty is in the human element of their selection, design, and continuing function (adoption and maintenance). These are dictated by public perception, neighborhood composition, participation of citizens in making their local needs and desires known to responsible City CIP project managers, and voluntary participation in design, construction, and maintenance of some structural stormwater control measures that can be accommodated on private property. Given that these BMPs require optional private citizen initiative and expense, they are amenable to incentive programs as well as promotion and marketing through public education and outreach from the City. The WPD Rain Catcher Pilot Program (RCPP) is in this category as it depends on a homeowner’s voluntary decision to adopt or participate in installation of a cistern or raingarden on their property funded by the City as an incentive. The benefits of the structural measure installation and operation can be estimated from existing models of their design. The level of participation would have to be estimated from behavioral factors.

The second set of these non-structural BMPs do not lead to a structural solution being implemented, but function almost entirely through the human decisions to act or refrain from acting on an existing quantifiable pollutant load. Sometimes this involves refraining from a polluting action like disposing of used motor oil on surfaces where it will be carried to storm sewers. When a human behavior creates a known pollutant quantity that will enter the stormwater collection system and stopping or amending this behavior reduces this load, a second pathway to calculate effectiveness may be possible. These BMPs require decision making of either all citizens, or specific citizen groups that may be influenced. This group would include the following types of BMPs:

- BMPs whose source loadings are probabilistic – voluntary secondary containment of stored materials that if exposed to rainfall generates runoff that should be captured for treatment. The pollutant loads are dependent upon the frequency, duration, and timing of rainfall. This might also include spill control practices that prevent buildup of pollutants between storm events. The pollutant load is then also dependent on the probability of spills.
- BMPs that are land use-specific – good housekeeping practices (commercial, industrial, transportation, construction) or integrated pest management practices (turfgrass, golf courses, nurseries, cemeteries, landscapes). Both the initial pollutant load (status quo) and BMPs are tied to the activities that occur on the particular land use. These BMPs control loadings dependent on decision making by management and staff of businesses or facilities of a particular land use.

- BMPs that depend on public/private design professional decisions – layout, retrofit for trash removal, impervious cover removal/disconnection, water conservation devices, purple pipe, GSI, rainwater harvesting, raingardens, secondary containment, and leak detection for underground storage tanks. These features can be included in development plans and designed to higher levels of pollutant load control and/or hydrologic remediation in watersheds based on decisions of design professionals. Within standard design practices and meeting codes and criteria, there is room for design decisions that can increase function and lower maintenance.
- BMPs that depend on raw rural land ownership decisions – land acquisition, conservation easements, native grasses, livestock control in riparian areas, specialized grazing, and riparian restoration. These BMPs can be implemented by landowners making conservation decisions on their own rural property. Many of these decisions may be incentivized by government programs and tax credits.
- BMPs that depend on awareness and voluntary expenditure of personal time like group sponsored cleanups, planting of trees and planting of other vegetation in critical areas of runoff.
- Programmatic BMPs that influence the behavior of the general public or specific subgroups. This would include the entire spectrum of education and outreach programs that seek to replace polluting behavior resulting in a stormwater load or loss of stream hydrologic function with more pro-environmental behavior. This would also include outreach to install residential scale distributed structural BMPs and low impact development practices. Residential scale voluntary projects such as disconnection of impervious cover through roof rainwater collection would be included.
- BMPs that are stormwater in nature but result in secondary conservation impacts in other areas (energy, water conservation, air quality, solid waste recycling) or co-benefits unrelated to pollutant load reduction and hydrologic remediation (carbon footprint reduction, heat-island amelioration, social capital benefits, community cohesion benefits). These BMPs would include those that induce pollutant reduction behavioral changes that produce pro-environmental behavior spill-over into other areas.

The unifying factor in this second set of BMPs is that programs can be designed to increase these beneficial behaviors through education, outreach, financial incentive, and behavioral “nudges” to remove barriers and promote attitudes that smooth the pathway to implementation. However, most of these BMPs also include a geographic attenuation factor as they occur at a residential location and the travel time and pathway dictate what portion of the load appears instream. If a distributed watershed model is calibrated for a watershed, the calculation of this attenuation may be automated.

The remainder of WPD masterplan solutions in Appendix A include regulations affecting development, municipal programs that directly or indirectly impact stormwater treatment, and source controls like City inspection and maintenance. In many of the solutions, there is an element of co-benefits or spillover in other realms such as carbon footprint, recycling, air quality, social capital, community solidarity, and connections to other City services.

Regulatory quantification of non-structural BMPs

In EPA’s guidance on Municipal Separate Storm Sewer System (MS4) permitting using TMDLs, the complexity of quantifying the impacts of what are essentially programmatic non-structural BMPs was noted because “many of these activities focus on source reduction and pollution prevention or behavioral changes that are difficult to translate into pollutant load reductions” (USEPA, 2008, p.103). Regardless, EPA maintained that such activities must be included in the TMDL BMP inventories but provided no clear guidance on methods of quantification for loading or loading reductions for any pollutants. An information/education component is one of the nine minimum elements of a watershed-based TMDL plan

as well as one of the six minimum control measures (MCMs) found in Phase II MS4s and Stormwater Management Plans (SWMPs) for Phase I MS4 permits (USEPA 2008). Receiving water monitoring is also mentioned as the method to determine SWMP and Stormwater Pollution Prevention Plan (SWPPP) effectiveness in EPA guidance; however, the instream monitoring found in MS4 permits does not isolate behavioral pollutant sources or load reductions from specific non-structural BMPs.

Original USEPA guidance on Waste Load Allocation (WLA) and Total Maximum Daily Loads (TMDLs) with stormwater as a loading source in rivers and streams does not mention education or programmatic interventions as BMPs (USEPA 1997). The TMDL information on the TCEQ website for the program provides some useful material but references EPA guidance that is vague and inadequate. The TCEQ TMDL program was contacted about non-structural controls that had been submitted in models used for TMDLs and they referenced the International Stormwater BMP Database (2018) as well as the North Central Texas Council of Governments BMP Library (NCTCOG 2019). The only non-structural BMP addressed quantitatively in the International Stormwater BMP database is the implementation of street sweeping programs. The NCTCOG Stormwater BMP Library includes references with links to resources from a wide variety of other agencies and associations and internally produced documents with such links. The library is only searchable within 11 categories of BMPs; however “non-structural” did not appear in any category. Neither database addressed quantitative benefits of non-structural controls uniformly (Strecker 1998; NCTCOG 2019; International Stormwater BMP Database 2018).

Guidance from USEPA in quantitatively evaluating non-structural BMP effectiveness may improve on the basis of the “reasonable assurance analysis” (RAA) approach that uses robust analytical modeling tools to identify the specific stormwater management practices that will be necessary over the long term to attain specified water quality protection requirements (USEPA 2017). RAA technical approaches are designed to be implemented through the NPDES MS4 permitting program and municipal stormwater program planning. One of the main features of this approach is the development of Improvement Goals that are quantifiable followed by a demonstration that proposed stormwater controls and management actions will attain these Improvement Goals. Also considered in the RAA technical approach is a step to document results to inform implementation, tracking and evaluation of success. The focus of the RAA approach is on long-term stormwater management plans and asset management systems that guide operations and new infrastructure projects. It appears to be similar to the OZ project in that it promotes SMART watershed and water quality goal planning and quantitative assessment of goal achievement. In essence, it appears to be USEPA’s effort to get away from the vague Maximum Extent Practicable implementation goals in MS4 permits. As with the OZ project, the RAA method provides a framework for comparing stormwater management alternatives, including different mixes of structural and non-structural BMPs, and different options for distributing them throughout the planning area. Another similarity is that the RAA modeling tools and iterative adjustments with new data are designed to reduce uncertainty over time. Similarly, the OZ project requires assessment of model predictions compared to ongoing monitoring of conditions into the future to adjust effectiveness assumptions for improved goal attainment simulations.

In a summary of 7 MS4 permits employing the RAA approach, USEPA noted that many of the models employed had previously been used for TMDL purposes (USEPA 2017). Unfortunately, some of the models selected are proprietary constructions, such as the Central Coast Regional Water Quality Board models for the Salinas, Monterey, and Pacific Grove CA MS4 permits employing the 2NForm stormwater management tracking system integrated with ESRI GIS by 2NDNature, Inc. This model purports to incorporate “objective performance evaluations” for hundreds of structural BMPs and widespread implementation of non-structural BMPs on parcels or roads. Unfortunately, the inner workings and supporting data for of the model software are opaque to review. Another RAA approach project was the Phosphorus Control Plan for discharges into the Charles River under the USEPA Region 1 Phase II General MS4 Permits. Phosphorus reductions to meet water quality goals were calculated for

municipalities in the Charles River TMDL which employed the SWMM model and a BMP Decision Support System (BMPDSS) to assist in BMP selection and sizing. Although the tools are represented to include non-structural BMPs, the summary description seems to only include “semi-structural” BMPs such as street sweeping, catch basin cleaning, organic waste and leaf litter collection programs, impervious area disconnection, and conversion of impervious area to pervious area (USEPA 2017). Phosphorus load reduction from outreach and education programs to foster behavior change in the population are not addressed.

The Washington Phase I MS4 Permit was also used as a case study of the RAA approach. For modeling, HSPF and SUSTAIN as modified by EPA Region 10, were used to assess water quality indicators, duration and peak flows for various return frequencies, and statistics representing peak and base flows over a long continuous period. Correlations between hydrologic metrics and the Benthic Index of Biologic Integrity (B-IBI) were used to predict future biologic health under multiple BMP scenarios. Results were compared to previously set standards for instream water quality and the percent exceedance of standards over 446 subwatersheds was minimized to suggest a stormwater management strategy. For biologic integrity, the probability of improving B-IBI scores above watershed standards was compared to existing condition and estimated fully forested (undeveloped) conditions using modeled hydrology. The quantitative use of non-structural controls was not found in this project summary although raingardens and cisterns were included. The Water Quality Improvement Plans for the San Diego region were also represented as RAA like in execution, but behavior change non-structural controls were lumped with other “non-modeled nonstructural BMPs” assumed to result in 10% wet weather load reduction for all parameters. However, load reductions and hydrologic metric changes were simulated separately for catch basin cleaning, downspout disconnection incentive programs, irrigation runoff reduction, rain barrels and street sweeping (USEPA 2017).

In a summary of 17 TMDLs with stormwater sources, USEPA noted several with public education as a component of the TMDL, but only one quantitative relationship concerning fecal coliform and pet waste (USEPA 2007). A 30% reduction in buildup of fecal coliform on landscaped, street, directly connected, and indirectly connected impervious cover land types was attributed to a public education program addressing pet waste removal. In this TMDL, the hydrology and non-point source pollution model SWMM was used incorporating buildup/washoff process estimates of pollutant loading into a dynamic simulation of runoff water quality. No reference was provided for an assumed pet waste or fecal coliform deposition rate or the 30% reduction in the EPA summary (USEPA 2007) or final Anchorage Alaska TMDL for Chester Creek (ADEC, 2005). Regardless, the pet waste education and outreach programs were used as one of only two Scenarios for load reduction in the TMDL. Another Anchorage document used as a reference made the assumption that the primary biogenic source of fecal coliform concentrations in surface waters was attributable to wild and domestic warm-blooded animal sources. However, the basis for this assumption was noted to be simply stormwater runoff analysis and lack of evidence for any other widespread sources (MOA 2003). No quantitative connection was attempted from the pollutant loading from pet waste to the behavior of pet waste pick-up to the influence of a targeted public education and outreach program to modify and increase the levels of pet waste pickup.

Bacteria TMDLs in Texas are common and often incorporate non-structural controls in Implementation Plans to reach their goals in *Escherichia coli* (*E. coli*) loadings. In the 2014 bacterial reduction plan for the Guadalupe River above Canyon Lake, domestic pet waste control, waterfowl controls, pigeon, swallow and grackle controls, street sweeping, storm drain marking, trash removal, and public education were mentioned as non-structural BMPs for stormwater. The analysis used HSPF to model the watershed and predict water quality (*E. coli*) from direct and land surface loadings. Model scenarios assumed a 30% reduction in loading from all changes in housekeeping practices including animal waste cleanup and street sweeping. No references were provided, or justification was attempted for the reduction percentage attributed to these measures (JMA 2014).

More locally, the TMDL for five assessment units in four Austin streams attributed E.coli loads to both managed and unmanaged animal populations in the watersheds. Pet population was calculated based on census tract human population, household size, and number of cats and dogs per household. However, no attempt was made in the TMDLs to allocate a portion of the current stormwater waste load to pet waste (TCEQ 2015). Subsequently, the Implementation Plan for the TMDLs incorporated national and literature survey data to get the corresponding E.coli load from dog ownership. The reduction in loads were then calculated for each related program separately using assumptions for effectiveness. Surveys of self-reported behavior change were extrapolated from a limited amount of data in one Austin park in the Bull Creek watershed to the TMDL watersheds.

The attempts to incorporate pet waste outreach programs quantitatively into TMDL watershed modeling illustrate the inherent difficulties of all non-structural BMPs. If a source amenable to reduction cannot be isolated and calculated accurately, then determining the effectiveness of any intervention to reduce it is moot. At best, these attempts acknowledged that only some land covers or land uses would generate a category of pollutant loadings (pet waste); therefore, spatially any assumed reduction could be apportioned to those land cover or land use categories.

Quantification of non-structural BMPs in industry publications

Non-structural BMP evaluation was considered briefly in development of the National BMP Database, which is a clearinghouse for effectiveness and efficiency data managed by the American Society of Civil Engineers and EPA (ASCE and EPA 2002). In compiling data for the first version, developers used an earlier literature review (Strecker and Quigley, 1998) concluding that no published studies were found that contained quantitative information evaluating the effectiveness of education and outreach BMPs in improving water quality. Even the current version only contains effectiveness data for non-structural controls of catch-basin cleaning and street sweeping (International Stormwater BMP Database 2018). Also, no efforts appear to have been made to reassess the literature studies on quantifying effectiveness of non-structural BMPs although it is mentioned on the website that “additional non-structural performance data are needed” (<http://bmpdatabase.org/performance-summaries.html>).

The Water Environment Federation (WEF) Water Environment Research Foundation (WERF) has conducted a number of studies to assist in the selection of BMPs and LID including several whole life cost models and a Toolkit for BMP selection (WERF 2009, 2012). However, non-structural controls including education and outreach were specifically excluded from consideration in the development of treatment algorithms for BMPs (WERF 2012). Earlier efforts from WERF included a study of tools to measure source control program effectiveness and documentation of stormwater demonstration projects in source control (WERF 2000, 2001).

The California Stormwater Quality Association (CASQA) has a well-developed effectiveness evaluation process for structural and non-structural BMPs (CASQA 2015). Targeted primarily towards MS4 permit holders, CASQA provides guidance on program development and improvement along with a source contribution database. Resources from the CASQA database include models, area loading factors, and references for a comprehensive list of pollutants (trash, nutrients, metals, bacteria, pesticides). This effort was useful in that it points out how many non-structural BMPs are without effectiveness data, and what assumptions have to be made in order to quantify their benefits absent relevant data. CASQA also published a survey on source contribution tools and methodologies (CASQA 2017). Since most source controls would be considered non-structural BMPs, this survey provided valuable information on the state

of the research on quantifying loads and load reductions. The survey elicited responses indicating that both loads and reduction estimation methods are inadequately supported for this category of BMPs.

Watershed Model Representations of Non-structural BMPs

Representation of nonstructural BMPs in pollutant loading, BMP selection and optimization, and watershed water quality modeling is highly variable. None of the most popular watershed models (SWMM, SWAT, HSPF) calculate non-structural water quality control load reductions in any comprehensive quantitative manner. However, the more simplistic stormwater BMP models and pollutant loading modules within watershed models sometimes cover quantitative methods for a few municipal programmatic BMPs. For example, street-sweeping that proceeds in a designed pattern with removal rates determined by scheduling, coverage, and equipment is often included in these models. In addition, most of the models now provide routines for calculating benefits of distributed Green Stormwater Infrastructure (GSI) that can be promoted for voluntary implementation through municipal education, outreach and incentive programs. Still, few of the available models can be used directly for non-structural controls that require behavioral change on the part of the public. Even those that do are lax in their documentation of adoption rates and quantitative methods to determine effectiveness. The model application literature and model user's guides were reviewed for instances where non-structural controls were addressed and a summary of this information is provided.

SUSTAIN

In the USEPA SUSTAIN model for BMP selection, source control actions such as street sweeping and pet waste management can be included; however, the land use characteristics in the land module or in an external model must be modified explicitly to represent changes in land management for these BMPs (Shoemaker et al. 2009). Alternative land use categories are used to represent areas with and without nonstructural BMPs but these cannot be included in the program's cost optimization tools. The only nonstructural BMP included explicitly in the land module of SUSTAIN is street-sweeping, and even then, the pollutant removal efficiencies must be specified by the user. Other area-based non-structural BMPs like impervious cover limitations, disconnecting impervious cover, minimizing fertilizer application, recycling rooftop runoff, or augmenting infiltration capacity through lawn management are also implemented through explicit changes in land use characteristics such as adjusting impervious areas, changing pollutant accumulation rates, or changing surface roughness characteristics. In SUSTAIN, the behavioral factors present in determining pollutant load or pollutant load reductions may also be applied through land use changes in the model input after calculating the requisite changes externally.

CLASIC

The Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) model provides continuous simulation of runoff water quality based on precipitation, evaporation, land use, soils, and topography using NRCS flow equations along with Horton infiltration and BMP effluent concentrations from the International BMP database. Outputs include life cycle costs, performance in terms of peak flow and volume reduction, and pollutant load reduction, and a multi-criteria decision analysis (MCDA) to compare co-benefits across scenarios of BMP selection (Zhang 2019). Currently only 6 BMP types are functional in the model; however, they include some structural Green Infrastructure BMP options that could be linked to non-structural BMPs. An example could be outreach to increase adoption rates of incentivized residential distributed BMPs such as rainwater harvesting and rain gardens. These BMPs are ubiquitous now in most watershed models that include structural BMPs at all. Although CLASIC has many unique features such as co-benefits analysis and flexible scale from neighborhoods to watersheds, it has no specific capabilities for including non-structural controls. It has a baseline-to-build scenario comparison tool that could be used with changes to the land use-specific and/or BMP-specific

parameters to approximate the impact of non-structural BMPs, but the cost and co-benefits output may not be valid as a result.

WMOST

The Watershed Management Optimization Support Tool 3.0 (Detenbeck 2018) is a relatively recent model developed by USEPA for optimization of expenditures for watershed-based water management. In this integrated model, water management is considered holistically and stormwater, water supply, and wastewater management are all combined in the tool along with optimization routines to enable scenario comparison. The non-structural BMPs in this model are discussed as “direct load reductions” and include street sweeping, tree canopy over turf/impervious land, and urban nutrient management. They are based on acres treated by each management practice. For each of the three practices, associated percent loading reductions are multiplied by baseline and managed runoff sets to calculate final runoff loadings to surface water as shown in the general equation below.

$$L_{(Ru,t)} = \sum_{i=1}^{NLu} \left[(bA_{l,s=1} \times L_{Ru,l,s=1,t}) \times \prod_{d=1}^{NDRSet} (1 - (P_{DR,l,d} \times P_{DR,d})) \right] \\ + \sum_{s=2}^{NLuSet} \sum_{i=1}^{NLu} \left[L_{Ru,l,s,t} - (L_{Ru,l,s,t} \times \prod_{d=1}^{NDRSet} P_{DR,d} \times bD_{DR,d}) - L_{Ru,l,s=1,t} \right]$$

where

N_{DRSet} = number of runoff loadings direct reduction sets

$P_{DR,l,d}$ = direct reduction for each land use, c , in direct reduction set, d , %

$bD_{DR,d}$ = binary decision variable for direct reduction set, d , 0 or 1

In the WMOST documentation, the following naming convention is followed in the constraint equations and objective function.

- The first capital letter indicates the type of quantity (e.g., Q=flow, A=area, L=loadings) except for decision variables that are preceded with the letter “b” (e.g., $bQ_{GwPumpAddl}$ =optimal additional groundwater pumping capacity).
- Primary subscripts provide additional information about the quantity by indicating
 - which component the quantity is associated with (e.g., R_{UseP} = revenue from potable water use) or
 - which components the flow travels between - the source component listed first and the receiving component listed second (e.g., $Q_{UsePWwtp}$ =flow from potable use to the wastewater treatment plant).

- Additional subscripts indicate elements of a variable. In the optimization problem, an individual variable exists for each element, but for documentation these subscripts facilitate brevity and clarity:
 - Variables that change with each time step have t subscripts. The number of variables in the optimization model equals the number of time steps for which data are provided and the model is optimized (e.g., for one year of data at a daily time step, 365 variables of that parameter exist in the mixed integer nonlinear programming model).
 - Additional subscripts are summarized as follows

u = different water users such as Residential and Commercial

l = different hydrologic response units HRU

s = sets of HRU types that include the baseline HRU set and other sets that have the same HRUs but with management practices implemented such as stormwater management including rain gardens and bioswales

c = different riparian buffer land use conversions

g = different relative loads groups for riparian buffer management levels

d = different direct reduction management sets such as street sweeping.

Although not mentioned, other non-structural BMPs could be handled in the same way if a direct percentage reduction in load for each pollutant could be applied for each land use for each non-structural BMP. These could be externally produced on the basis of adoption rates for BMPs and their effect on pollutant loads for certain land uses. The model does not presuppose any relationships that could be used for behaviorally directed BMPs. It provides a framework for including non-structural BMPs alongside structural BMPs but goes no further.

SELECT

The (BMP- SELECT 2.0) model is a spreadsheet-based web-tool developed by the Water Environment Research Foundation (WERF) for EPA. It is a simple planning level tool that allows comparison of alternative scenarios for controlling stormwater pollution and the whole life cost associated with each scenario. Structural controls are emphasized although a Generic user-defined option is also encoded. Flexibility is limited and even the Generic option is defined by parameters from influent/effluent Event Mean Concentration (EMC) and Water Quality Capture Volume/drawdown time based calculations of water quality benefits.

The SELECT model was chosen for the Shoal Creek Conservancy Watershed Protection Plan due to its focus on limiting the extent and complexity of input data needed to generate results for pollutant loadings and BMP effectiveness within a defined watershed area (Doucet & Associates 2019). Loadings and Load Duration Curves (LDC) were developed for phosphorus, nitrogen, TSS, fecal coliform and *E. coli* under current and future land uses. Subsequent use of the model was mentioned for parsing causes and sources of pollution, estimating load reductions from potential management strategies, and documenting performance of alternative stormwater management. Although not included in the draft modeling report, an effort was made to find methods to incorporate non-structural BMPs and their load reductions into the

modeling. The available methods researched were insufficient for quantitative use in the SELECT model, but their load reduction may be estimated separately and incorporated into the WPP (2019 Sep 21, Tom Hegemier, Doucet & Associates, personal communication).

CWOT

The Clean Water Optimization Tool (CWOT) was developed by the Center for Watershed Protection to assist a group of communities on the Eastern Shore of Maryland in meeting stormwater pollution reduction strategies to meet Chesapeake Bay TMDL requirements. The tool includes land use change BMPs and can simulate municipal programmatic strategies that have unique pollutant removal crediting formulas. As with CLASIC, some distributed Green Infrastructure BMPs such as rainwater harvesting, stormwater planters, downspout disconnection, infiltration practices, and rain gardens are included specifically. Land use change BMPs include tree planting, impervious cover removal, urban cover crop, and soil augmentation. Municipal programmatic strategies included pet waste programs, street sweeping, outfall netting, living shoreline, and stream restoration. Pollutant removals for most of these options are calculated by using guidance from the Chesapeake Bay Project Expert Panel on Stormwater Retrofits (Schueler and Stack, 2012). However, pet waste program pollutant removal as an example of behavior based non-structural BMPs was calculated using methods developed for the Watershed Treatment Model (Caraco, 2001, 2013) and assumptions from the Bacterial Implementation Plan for the James River and Tributaries – City of Richmond (Maptech, 2011). From the resulting narrative formula for pollutant loading reductions, there are numerous behavior-based assumptions embedded in the calculation:

*Annual lbs of pollutant removed per area of interest = # of bags/yr * waste production (lbs/dog/day/area of interest) * concentration of pollutant in dog waste (lb/lb) * fraction of daily waste captured per bag * fraction of pollutant delivered to stream * fraction of bags used to properly dispose of pet waste * 365 days/yr * fraction of dog walkers who rarely clean up after their dogs (CWP, 2015)*

Although reference is made to data supporting discount factors for some parameters (Swan 1999), CWOT does not provide any coordinated methods for accommodating non-structural BMPs.

WTM

The Watershed Treatment Model (Caraco 2001, Caraco 2013) was developed by the Center for Watershed Protection (CWP) for USEPA in spreadsheet format. It included a stepwise process of determining primary and secondary sources of pollutants, specifying existing and future management practices, stormwater retrofit input, and future land use and new development input. Although simplistic in calculation methods, it included a variety of secondary watershed sources such as urban channel erosion, illicit connections, sanitary sewer overflows, on-site sewage facilities, livestock, marinas, road sanding, and non-stormwater point sources. For watershed practices, it includes many that are non-structural BMPs such as residential turf management education, pet waste education, street sweeping, residential impervious cover disconnection, urban downsizing, SSO repair/abatement, OSSF education/repair/upgrade/retirement, and illicit connection removal. For future practices, it also included the ability to use discount factors such as an Awareness Factor applied to educational programs. However, default assumptions for many of the practices are not documented in the model and the user must provide support for any values used for them and the associated discount factors.

SWAT

The Soil Water Assessment Tool (SWAT) is a well-documented and supported public domain model used to simulate the quality and quantity of surface and ground water and predict the impact of land use, land management practices, and regional management in watersheds. SWAT has highly detailed specification of management practices related to irrigation, tile drains, fertilization, crops, grazing, pesticide use, turfgrass, landscaping, prescribed burns, and soil management. All of these may be influenced by education and outreach to the individuals, businesses, and groups that are responsible for controlling these

mostly agriculturally based activities. Any modification based on behavior change due to education and outreach would have to be calculated outside the program and used to control the many knobs on each management practice. However, for urban non-structural BMPs, SWAT only includes street sweeping explicitly. It allows for simulating street-sweeping only when using the build-up/wash-off algorithm to calculate non-point source pollutant loads. The model includes both sweeping equipment selection and corresponding removal efficiencies for six pollutants (Arnold et al. 2011).

A modeling guide for conservation practices was prepared for SWAT and APEX models that included pet waste management along with several other “non-structural” BMPs that primarily applied to agricultural practices. In this guide, pollutant removals were hardwired at 80% TN and 90% TP for pet waste management (Waidler et al. 2011). Reference was made to the USEPA STEPL model (Spreadsheet Tool for the Estimation of Pollutant Load) for these values; however, this reference only discussed livestock and farm animals and required direct entry of animal population by watershed (Tetra Tech 2018).

In the COA proof of concept modeling evaluation of hydrological benefits from distributed approaches to stormwater management, SWAT was used extensively. Cisterns and raingardens were evaluated at three implementation levels and hydrologic metrics were compared. At the highest implementation level the watershed at 42% impervious cover behaved hydrologically (using baseflow, peakflow, and rate of change) closer to that expected for a lower impervious cover (20-30%) watershed (Glick et al. 2016). A subsequent study established hydrologic equivalency between one decentralized and two conventional centralized control service delivery models and compared hydrologic and water balance metrics. SWAT model scenarios showed reduction in surface flow and number of water stress days as well as increase in lateral flow and evapotranspiration in the decentralized service deliver over both centralized service delivery options. The hydrologic metrics were not substantially different among scenarios (ERM 2018). Finally, the SWAT model was used to compare the decentralized service delivery model characterized as an infiltration scenario against two centralized sedimentation/filtration scenarios. The hydrologic metrics used were found to be confounded and inadequate for judging the specific differences between infiltration and filtration structural BMPs. In addition, the SWAT model was found to be inadequate primarily because its inability to simulate actual spatial distribution of stormwater controls. Recommendations were provided to improve the equivalency analysis, modify the list of hydrologic metrics selected for analysis, use a spatially explicit watershed model and expand the dimensions of performance comparison to include other quantitative and qualitative measures relevant to stakeholders, design engineers, and the City (Porras et al. 2019).

SWMM

The current version of this popular urban stormwater model (ver. 5.1) is used for planning, analysis, and design related to stormwater runoff, combined stormwater and sanitary sewers, gray infrastructure of pipes and storm drains, green infrastructure, and gray/green hybrid stormwater controls. It constructs watersheds through an area/node/conduit network. SWMM calculates runoff, infiltration, percolation, interflow, and reservoir routing as well as generating nonpoint source pollutant loadings. However, a recent review has indicated that SWMM may lack some capabilities in realistically simulating diffuse pollutant sources, their fate and transport and the effectiveness of Green Stormwater Infrastructure/Low Impact Development in distributed applications (Niazi et al 2017). Due to its structure, it suffers from the same problems as SWAT in simulating actual spatial distribution of stormwater controls.

Categories of non-structural controls that have been suggested to be modeled through SWMM include vegetation and landscaping, minimizing site disturbance, impervious area management and time of concentration modifications (Asghar and Garg 2018). Quantifying benefits from educational and incentive programs in these areas would still require a behavioral model to determine the degree of voluntary participation in each non-structural BMP. SWMM has been used by the City of Austin in the

study of BMPs for individual watersheds, decentralized green infrastructure, and on-site erosion detention (WPD 1995, 1997, Geosyntec 2017a, 2017b, 2017c, HDR 2007, 2011). The pollutant load reductions from Green Stormwater Infrastructure (GSI) could be estimated through SWMM. However, the voluntary adoption rates for GSI with or without incentives at a residential scale are a function of individual land-owner choices. These behavioral components necessary to quantify the benefit of an educational or incentive program are not directly modeled by SWMM.

HSPF

The USEPA has supported HSPF in watershed modeling in combination with its BASINS 4.5 for standardized watershed data (Bicknell et al 2005). It has been used in many Total Maximum Daily Load (TMDL) studies that often include assessments of non-structural BMPs.

In one of the bacteria and nutrient TMDL referenced by EPA, the HSPF model was used to estimate the bacteria load from domestic pets (USEPA 2007). The numbers of dogs and cats within the basin were used to estimate bacteria load. However, the modeling report does not explain how the model was used to generate the loads (USEPA 2005). As with the Anchorage SWMM model, a build-up/storage/wash-off routine was used to model non-point source pollutants. In several TMDLs using HSPF, the USGS outlined method to model fecal coliform including population-based methods to generate pet waste loads as well as wildlife loads (USGS 2003a, 2003b, 2003c, 2003d). A feature in HSPF has routine ACCUM used to quantify buildup of bacteria on the surface on watershed areas:

$$ACCUM = (Fprod * FCden)POPN/HAB$$

Where:

ACCUM = the fecal coliform bacteria accumulation rate (number of colonies/acre/day),

Fprod = the feces produced per day (g/day),

FCden = the number of fecal coliform bacteria per gram of feces produced (number/g),

POPN = the population size, dimensionless, and

HAB = the habitat area (acres).

In HSPF, ACCUM is bound by a storage limit (SWOLIM) used to account for die-off of bacteria stored on the land surface. In USGS TMDLs, this limit was used to simulate a decay rate of 0.1 day^{-1} . It was also noted that in many cases POPN or FCden are used as calibration factors. On average, one dog generates 450 g of feces per day (Weiskel and others, 1996), and an estimated 4.11×10^6 col/g of feces (Mara and Oragui, 1981).

Regionally, HSPF has been used in many TMDL studies in Central Texas (TCEQ 2007, 2016, 2018, JMA 2014a, 2014b). In each TMDL, non-structural controls are used in implementation plans; however, few take credit for a specific quantity of load reduction from these BMPs or attempt to model their usage (TCEQ 2016, 2018).

SPARROW

SPARROW (SPAtially Referenced Regressions On Watershed attributes) is maintained by the U.S. Geological Survey. It spatially references various watershed components, such as stream monitoring data, pollutant sources, etc., to surface water flow paths that are defined by a digital drainage network. It then imposes mass balance constraints to empirically estimate terrestrial and aquatic rates of pollutant flux.

Applications of SPARROW include estimation of the spatial distributions of pollutant yields, pollutant sources and the potential for delivery of those yields to receiving waters. This information can be used to:

- predict ranges in pollutant levels in surface waters,
- identify the environmental variables that are significantly correlated to the pollutant levels in streams,
- evaluate monitoring efforts for better determination of pollutant loads, and
- evaluate various management options for reducing pollutant loads to achieve water-quality goals.

SPARROW has been used previously to estimate the quantities of nutrients delivered to streams and watershed outlets from point and nonpoint sources over a range of watershed sizes. This approach embedded in SPARROW not only uses process-based models to simulate transport of pollutants, but it also uses the actual historical monitoring data and known predictor variables to predict the various model input parameters. In this manner, a more realistic model can be developed that closely describes the conditions of the particular watershed (Schwarz, et al., 2006). Locally, little use of SPARROW has been made in the TMDL program likely due to the absence of instream data for regression analysis in watersheds under investigation. The most common applications including non-structural BMPs have been in large agricultural watersheds employing different levels conservation measures (Garcia et al 2016). Although “spatially referenced”, it is too large scale and generalized for application to the size of watersheds to be evaluated in the Austin area.

Other models with non-structural BMP options.

Several other models have accommodated specific non-structural BMP loads; however, they require assumptions that limit their utility in BMPs with a behavioral component. These include the STEP-L, PLOAD, L-THIA and GWLF-E. PLOAD is a simple EPA method that uses adjustments downward for EMCs in particular land uses to account for pollutant removals from structural and non-structural controls. STEP-L (Spreadsheet Tool for Estimating Pollutant Load) also uses land use to set user-specified BMP efficiencies rather than actual simulation of processes. A priori knowledge of pollutant load removal efficiencies is most often lacking for non-structural controls. L-THIA (Long-Term Hydrologic Impact Assessment) aggregates BMPs and assigns a change in curve number (CN) value to simulate the action of structural and non-structural BMPs. It uses calculated flows from NRCS method with user-defined EMCs by land use to calculate loads. Supportable values for changes in CN are even less likely to be available for non-structural BMPs than changes to EMCs. GWLF-E (Generalized Watershed Loading Functions) is the base model for a number of applications including MapShed. This application is promoted by USEPA in the “Model My Watershed” web app portion of their “WikiWatershed” web toolkit to support citizens, conservation practitioners, municipal decision-makers, researchers, educators, and students to collaboratively advance knowledge and stewardship of fresh water (Stroud, 2020). The model uses build-up/wash-off coefficients to calculate loadings and allows BMPs to be applied at variable intensities as long as reduction coefficients are known for each BMP.

Unfortunately, these BMP-specific reduction coefficients are not available for non-structural behavior-change based BMPs although they may useful for structural with a behavioral component such as a precursor education and incentive program. In all the models discussed, it is evident that non-structural BMPs have been an afterthought and the range of non-structural BMPs is not considered. The non-structural BMPs most often included for representation are street sweeping, pet waste control, residential green infrastructure, and any regulatory improvements that can be supported with a change in land use based impervious cover, curve number, or EMC. Non-structural BMPs that require behavior change (with the exception of pet waste management) are for the most part absent from consideration in most applications of watershed and loading models.

Non-Structural BMP Effectiveness Studies

The literature on BMP effectiveness studies addressing non-structural controls was primarily found in regulatory and regional agency development documents and specific watershed applications. These sources most often addressed effectiveness of a range of non-structural BMPs together and provided some guidance to municipalities and stormwater discharge permit holders (MS4s) on how to perform and sometimes monitor non-structural BMPs. Unfortunately, most of the studies did not attempt to arrive at actual values or methods to quantify the hydrological or pollutant loading effects for the range of non-structural BMPs they addressed.

Prince George's County, Maryland Department of Environmental Resources (PGDER)

One of the earliest studies of non-structural BMP effectiveness tested the assumption that outreach programs directed at changing the behavior of residential property owners can have an impact on reducing nonpoint pollution associated with such activities as lawn and garden care, car care, and disposal of yard wastes and household chemicals. Prince George's County, Maryland's Department of Environmental Resources (PGDER) conducted a comprehensive public education program over a 5 year period in the early 1990's. PGDER attempted to measure the effectiveness of outreach efforts through before and after program surveys, by using a water quality modeling assessment tool and, by monitoring the water quality of the receiving waters before and after the outreach program. The study determined that the effectiveness of an outreach program depends greatly on the level of funding available to sustain efforts on a long-term basis, the types of outreach venues used, and tailoring outreach programs to address unique issues and socioeconomic factors in the target community. It was found that even with the intensive educational effort of this program, lasting over one year, the degree of change was marginal. The cost of a multifaceted targeted education program was far greater than anticipated, and cost prohibited implementation of the program on a countywide basis. Quantifying and understanding the fate and transport of urban pollutants and the effectiveness of the outreach efforts also proved to be both complex and difficult (Coffman 2001).

Western Australia effectiveness baseline documents

An early effort abroad to quantify non-structural BMP benefits in general was funded by the Australian state of Victoria through a Cooperative Research Centre for Catchment Hydrology. The Centre produced a number of reports in this subject area including an overview document, a benchmarking survey, a literature review, and monitoring guidance manual (Taylor and Wong 2002a, 2002b, 2002c, 2003). These were completed in roughly the same years as the development of the BMP database mentioned above in the US (ASCE and EPA 2002). A useful construct from this study was the categorization of non-structural controls into five basic groups (Taylor and Wong 2002a, Taylor and Fletcher 2007):

1. Development regulatory controls such as impervious cover limitations, setbacks from creeks, requirements for private structural BMPs, etc.
2. Permitting and Enforcement regulatory controls such as sedimentation and erosion controls on building sites, illicit discharge penalties, site inspections, etc.
3. Pollution prevention programs such as spill control and permitting for businesses using storm sewers, etc.
4. Strategic planning and government controls including city-wide management of drainage utility funding to support implementation.
5. Education and outreach to direct targeted campaigns to schools, neighborhoods, and special populations as needed and indicated by area and type of stormwater water quality problems observed or measured and prioritized.

These groups are recognizable within the WPD organization and the WPD Masterplan FY2015/2016 Update (WPD 2015). Taylor and Fletcher (2007) also noted two modes of operation. Non-structural controls can operate both as tangible, on-the-ground strategies (e.g., street sweeping, the preservation of vegetated buffer zones along waterways within new urban developments, or local certification and training programs) or higher-level strategies that eventually result in on-the-ground stormwater management measures, be they structural or nonstructural (e.g., ordinances that require stormwater reuse in new buildings, land development code promoting GI/LID, citywide stormwater management plans, or stable funding mechanisms for local stormwater management programs including education and outreach).

The Australian study also identified the impediments to evaluation of non-structural BMPs many of which are acutely applicable to the education and outreach category. These impediments include the inherent difficulty in monitoring BMPs that seek to change people's behavior which is another distinguishing factor used to categorize types of non-structural BMPs (ASCE and USEPA 2002). This factor separates non-structural BMPs into two broad bins of "institutional controls" (items 1-4 above) and "behavioral controls" (education and outreach) in designing monitoring plans (ASCE and USEPA 2002). Such monitoring would be necessary in order to refine and validate a predictive model. The confounding issues that cannot be controlled in an experimental design studying public education as a pollutant load reduction method make it virtually impossible to evaluate directly although it may be monitored in some situations using trend data (ASCE and USEPA 2002). These issues include the logistical problems of using an observational approach (privacy, timing, manpower), the differences between observed behavior and self-reported behavior, the incongruities between attitude and behavior, difficulties in managing a control site, and the change of a studied area with time (Taylor and Wong, 2002d). This factor may make mixed-methods or qualitative study designs attractive (Rubin and Baddie, 2015); however, qualitative study methods will not be a direct route to developing a quantitative model comparable to that used with structural BMPs. Although, the universe of non-structural controls is large and diverse, their selection and the use may be hindered by their life-cycle costs, uncertainty with respect to their performance and how this varies over time (Taylor and Fletcher 2007).

A particularly useful contribution of the Australian series was the survey of 40 urban stormwater managers in both their country and overseas (Taylor and Wong, 2002c). Unpublished case studies and industry evaluations were sought regarding the evaluation of non-structural BMPs that would otherwise not have been documented. Although the level of confidence and experimental support for some of these data may be questionable, the experience of these stormwater managers may be appropriately used with caveats qualitatively until improved information is available. Survey questions were used to create a Value score for each of 41 types of non-structural BMP based on perceptions of effectiveness, efficiency and practicality from the survey rating scores converted to % with weightings given by the authors via Best Professional Judgement (BPJ) for each factor.

$$Value\ score = [(D \times W_d) + (T \times W_t) + (E \times W_e) + (P \times W_p)]/20$$

Where:

Value score = out of 100, with a high score representing a high relative value.

D = the current degree of the measure's use (%)

W_d = the weighting for attribute D (2/10) using Best Professional Judgment (BPJ)

T = the current trend of increasing use (% of survey respondents reporting an increase in use)

W_t = the weighting for attribute T (3/10)

E = perceived effectiveness, efficiency, and practicality (%)

W_e = the weighting for attribute E (10/10)

P = the degree of promise for future use (%)

W_P = the weighting for attribute P (5/10)

These surveys were supplemented with further contacts in some cases and interview information with some professionals was included in the literature review document citing about 200 references (Taylor and Wong, 2002b). The overall finding from the literature and case studies was that a balanced, synergistic mix of structural and non-structural BMPs is preferable at both the catchment and city-wide scale with a targeted, intensive, and interactive community education and participation program being one of the top eight non-structural BMPs in terms of value (Taylor and Wong, 2002a). This conclusion is somewhat surprising (and unhelpful quantitatively) given the overall disappointment displayed with the predictive power of any quantitative method of evaluation for any non-structural BMPs and education and outreach in particular. The conclusion mirrors that found in regulatory guidance that promotes education and outreach as an essential part of any municipal stormwater management but fails to give any values of benefits attributable to it (USEPA 2019).

Despite the negative appraisal of the direct evaluation of public education as a pollutant load reduction method, the Australian study series developed both a conceptual model for evaluating how all non-structural BMPs may improve stormwater quality and seven different styles of evaluation to accommodate multiple non-structural BMPs effectiveness on stormwater pollution using monitoring data. However, this “evaluation framework” was also disappointing as it simply traced the steps in implementation of a non-structural BMP from awareness and/or knowledge, self-reported attitude change, self-reported behavior change, actual behavior change, stormwater quality change, and ultimately to waterway health change. The final recommendation that monitoring should if possible be based on the last three styles of evaluation almost sounded disingenuous because in its coverage of public education and outreach the literature review began with references citing the absence of links between environmental beliefs and attitudes and change of behaviors (Taylor and Wong, 2002c, p. 43). Also, the literature review pointed to self-interest and economic considerations being more important determinants than resource conservation or altruism. The reviewers also indicated that stakeholders responsible for funding or managing education programs are prone to report success despite poor definition of objectives, poor evaluation protocols, and inconclusive findings (Taylor and Wong, 2002, p. 44). Another problem with data analysis and reporting in evaluation of public watershed education programs is consistency if lasting over several years. Typically, the stakeholders responsible for initiating and conducting these programs are not familiar with the routine academic requirements for data quality control for the long term. This leads to difficulties when the project results are to be published (Taylor and Wong, 2002c).

After reviewing this 2002 effort in examining the potential for quantifying water quality benefits of watershed education, the logical decision would have been to give up. However, after digging deeper into the case studies documented in the literature review, the picture painted by the report writers was not so grim. Much of the poor report for quantitative measures revolved around the very low percentages of behavior changes reported and observed for the given percentage awareness changes reported via survey instruments. They were also disappointed at the low minimum and very large ranges for actual behavior changes relative to reported awareness changes due to education reported via surveys. However, the descriptions of many of the programs they found both in Australia and the US indicated that a significant beneficial impact was still being made by education and outreach, it was just elusive, hard to quantify, and even harder to consistently predict (Taylor and Wong, 2002c). Another unquantifiable factor relayed by the stormwater managers interviewed in the project was the undeniable influence of public education on other programs and projects that were secondary to the thrust of the watershed education program itself. This included the synergistic effects of education on enforcement programs, new regulations, and short-term behavior modification such as drought response (Taylor and Wong, 2002a). This was found in other literature where education directed at single one-time behaviors such as with programs for installation of water-saving devices, rain barrels, or rain gardens, which have a measurable and

modellable impact, could be used rather than programs directed at consistent long-term behavior change, such as dog waste disposal (Moore and Boldero 2017). Therefore, returning to the influence of education on behavior and carrying through individual behavioral impact on pollutant loading still appeared to be worth reassessment of literature if those individual impacts of behavior change can be aggregated into a distributed watershed model for comparison with structural BMPs.

Portland Effectiveness Evaluation

The City of Portland recognized a need for an effectiveness evaluation of BMPs to document ranges and default values for all those practices to be used in management of stormwater quality and quantity in the city (BES 2006). Portland collected data on structural, non-structural, and instream BMP effectiveness to extrapolate beyond regional, national, and literature data and derive values specific to Portland for each BMP. The most effective non-structural BMPs were categorized by stormwater management improvements using effectiveness in load reduction for four pollutants, TSS, dissolved zinc, *E. coli*, and total phosphorus. Effectiveness was also considered for controlling stormwater flowrates and volumes, temperature, and aquatic and terrestrial habitat improvements as shown in Table 1. For most non-structural controls, the effectiveness was expressed in terms of unitless multipliers that act only in concert with other calculated BMP efficiency values. For public education, multipliers were applied to total loading of pollutants, applied to loadings specifically generated by a particular land use, or applied as a multiplier on other BMPs to indicate higher rates of application as influenced by awareness and buy-in of contacted group. This effort had some value in that it initially focused on BMPs with the least amount of data, primarily non-structural BMP, and it ultimately sought to develop a comprehensive listing of BMPs. Unfortunately, the resulting coefficients were determined mostly by Best Professional Judgement and consultation with other watershed professionals. The multipliers could not be independently verified. They would be difficult to apply in a deterministic water quality or hydrological model. The initial review of BMP types included the following:

1. Zoning, E-Zones
2. O&M
3. Buffer protections
4. Street sweeping
5. Facility cleaning
6. Technical assistance
7. Stewardship
8. Educational programs – Business and Residents
9. Educational programs – City Employees and other agencies
10. Impervious surface reduction
11. Downspout disconnect
12. Erosion prevention
13. Parks vegetation management
14. Truck washing
15. Spill response
16. Ditch and channel maintenance
17. Leaf and needle pickup
18. Landscape management practices.

Table 1
Portland Effectiveness Evaluation – Most Effective Non-structural BMPs

Stormwater improvement	Non-structural BMPs
Flow reduction	<ul style="list-style-type: none"> • Revegetation • Development requirements for infiltration and revegetation
Volume reduction	<ul style="list-style-type: none"> • Development requirements • Reduction of impervious surfaces
Habitat improvement	<ul style="list-style-type: none"> • Protection of stream buffers through regulation
Temperature reduction	<ul style="list-style-type: none"> • Protection of stream buffers through regulation
Pathogen management	<ul style="list-style-type: none"> • Public education • Pet waste programs
TSS removal	<ul style="list-style-type: none"> • Street sweeping • Maintenance of MS4 system components • Erosion control • Development regulation
Nutrient reduction	<ul style="list-style-type: none"> • Street sweeping • Maintenance of MS4 system components
Dissolved metals management	<ul style="list-style-type: none"> • Street sweeping • Downspout disconnection

When faced with determining an effectiveness value for public education in changing behavior of the public, Portland contracted a recommendation from consultants who performed a literature review. The consultants recommended values from return rates from brochure distribution and website hits from print/radio ad campaign on native plant use. The brochure mailout had a response rate of 8% and the ad campaign had an internet response rate of 1.5 percent which was recommended as an effectiveness value for any Portland media campaign promoting change in citizen stormwater management behaviors (HECI 2006). If this low rate of response is accurate for all non-structural BMPs with a behavioral component, the lack of interest in quantifying load reductions would be understandable. Yet all MS4 permits contain the same requirements for non-structural BMP implementation.

Chesapeake Bay Stormwater Performance Standards

The work performed as part of the Chesapeake Bay Project funded through EO 13508 in 2009 has resulted in many advances in stormwater management associated with nutrient loading reductions required to protect the regions waterways. One study that has been cited often was the University of Maryland's Adoption of Household Stormwater Best Management Practices. Primarily directed towards non-structural education and incentive programs for rain gardens and cisterns, survey responses and sociodemographic data were used to examine adoption rates, awareness to adoption ratios, influence of gardening participation, environmental concern, barriers to adoption, and methods of incentive delivery. The study found that adoption rates for all household stormwater BMPs were low especially rain gardens (2.5%) and rain barrels (7.6%) and that a 50% rebate could be expected to triple adoption rates (Newburn et. al. 2014). Additional survey data was collected in two suburban watersheds in the area to understand the underlying social factors that may act as barriers to stormwater BMP implementation. The study found that renters and members of homeowner's associations were less likely to implement household BMPs independent of knowledge, possibly reflecting the perceived or real bureaucratic or procedural barriers to good stormwater management" (Maeda et al 2018). Figure 1 shows the approach used in this study.

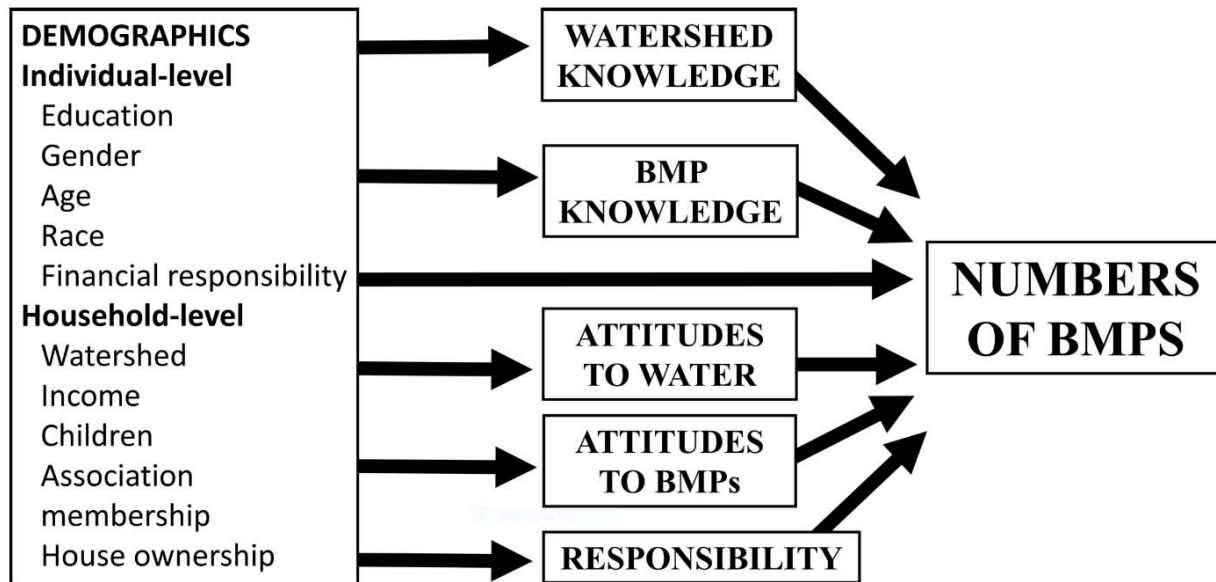


Figure 1 Conceptual approach to Chesapeake Bay study of linking residential stormwater BMPs to social factors

The BMPs evaluated in this study included reducing fertilizer, downspout disconnection, natural landscaping, lawn infiltration, pervious paving, rain barrels, lawn depression, and rain gardens. All of these would be considered non-structural if connected with education or incentive programs in suburban areas. The study found a total adoption rate of 8.0% for rain barrels and 3.7% for rain gardens. This could be compared to rates of 7.5% for rain barrels and 3.1% for rain gardens found in Columbus, Missouri (Shin and McCann 2018).

In 2010, the Chesapeake Bay Program (CBP) launched a number of expert panels on quantifying BMP pollutant loading reductions that could be used as verifiable credits for Chesapeake Bay communities with NPDES MS4 permits. The panels followed a specific protocol for the development, review, and approval of loading and effectiveness estimates for BMPs that would be used in input for the next phase of the Chesapeake Bay Watershed Model (WQGIT 2014). The CBP Water Quality Goal Implementation Team commissioned a consultant (Tetra Tech) to evaluate the feasibility of convening an expert panel on the use of education and outreach as an urban BMP (DeSantis 2015). Tetra Tech key word searched through the EBSCO research database and Google Scholar, but was forced to resort to primarily gray literature searches through Google, using USEPA's online Nonpoint Source Outreach Toolbox, recommendations from an earlier panel on defining removal rates for urban nutrient BMPs, and responses from the NPSINFO listserve operated by USEPA. The result was a literature review of 57 sources focused on monitoring data for outreach targeting behavior changes in residential fertilizer use, pet waste disposal, septic tank maintenance, car washing, disposal of grass clippings, and proper use of marina pumpouts. Just looking at these six non-structural BMP outreach programs, the overall findings of their report were not encouraging. The literature showed a lack of water quality monitoring data to support outreach results, a lack of consistent, statistically significant behavior change results, a lack of data from the Chesapeake Bay watershed, and not enough monitoring data for an expert panel to work with. Reasons given for this lack of data included the following:

- Education and outreach is most often conducted by local agencies that do not have water quality monitoring capabilities.

- Outreach is typically underfunded making them unable to afford statistically valid before-after studies, paired watershed studies, or downstream monitoring for treatment watersheds.
- Outside variables such as unpredictable rainfall patterns, changes in watershed land use and development patterns, and rapidly growing populations make pinpointing causes of water quality degradation or improvement difficult.

It is unfortunate that the CBP has not undertaken an expert panel to quantify stormwater pollutant removal credits for education and outreach. However, it is understandable given the difficulty in linking behavior changes to long-term water quality improvements. Regardless of these difficulties, it was still recommended that the CBP link outreach efforts to water quality monitoring in some way and use a statistically valid before/after analysis to indicate effectiveness (DeSantis 2015).

CASQA Effectiveness Assessment.

The California Stormwater Quality Association Effectiveness Assessment (EA) approach uses a series of six categories of outcomes to create a consistent scheme for assessing individual outcomes. The outcomes represent a progression of conditions that are assumed to be related in a sequence of causal relationships. They are basically the levels of organization where an improvement to water quality would be evident or supported by evidence. Figure 2 gives a summary of this structure.

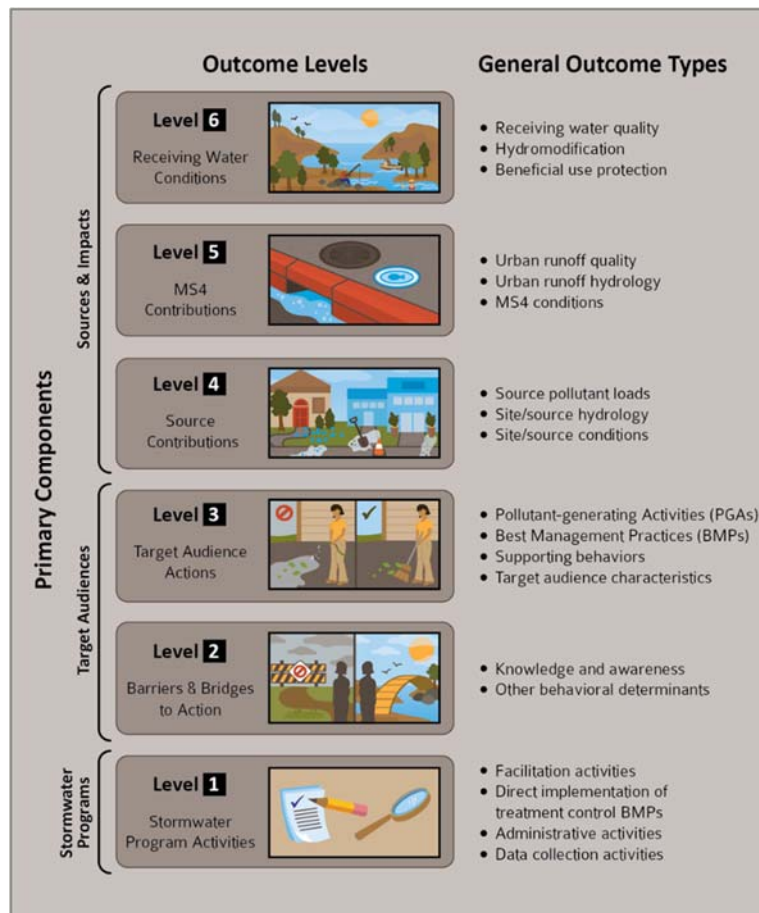


Figure 2. Outcome levels of the CASQA Effectiveness Assessment.

Although the ultimate goal is to see improvements in Level 6, change at this level is rarely quantified in monitoring. Level 5 outcomes are often monitored and can sometimes be modeled through process-based BMP loading models. Level 4 is where monitoring becomes less valuable and is less prevalent in an ongoing program basis. Modeling source contributions is an option, but as discussed above, it rarely represents quantitatively the sources that non-structural BMPs would address. Levels 1-3 are most often where non-structural BMPs would act on Pollutant-Generating Activities (PGAs) through behavior changes in the population at large. In particular, CASQA references problem awareness and other behavioral determinants under outcome level 2 (Barriers and Bridges to Action).

The elaborate guidance documents and descriptive material contained in the CASQA EA program is valuable; however, very little of the material contains quantitation of source loadings or the impact of non-stormwater BMPs on those pollutant loadings. In surveys of MS4 permittees about source contribution tools and methodologies in 2017, the expected problems with quantification were expressed (CASQA 2017):

- Load reductions are very hard to characterize
- Percent reduction is not a legitimate way to characterize certain source control activities
- Baseline loading estimates are imprecise
- Methods for valuing/crediting all source controls do not exist.
- Lack of monitoring data to substantiate assumed load reductions
- Load reduction from source control is dependent on pollutant.
- The accuracy and consistency of loads and load reduction from BMPs suffers from being too subjective.

The survey also identified the following methods of interest for loading factors and quantification of source control load reductions (2017):

- Literature values and scaling to local characteristics
- Compliance rates
- Quantity of waste diverted
- Surveys of behavior and extrapolation to full service area

What was provided was essentially a characterization of need rather than a solution method to quantify the source loadings and loading reductions from source control non-structural BMPs. Regardless, CASQA also provides a repository of resources for literature values purported to characterize source contributions and pollutant load removals, direct measurement of source contribution through monitoring and special studies, and information on both complex and simple spreadsheet models useful in modeling source contributions and source control effectiveness (CASQA 2019). Although presented as a database, it is a reference management tool to access documents primarily in gray literature reports.

San Diego Water Control Improvement Plans

A more recent relevant project for quantifying and modeling non-structural BMP benefits including watershed education and outreach was undertaken by the City of San Diego in meeting compliance obligations for its Municipal Separate Storm Sewer System (MS4) Permit under the federal Clean Water Act and California's implementation of it through Order No. R9-2013-0001 (Regional MS4 Permit). San Diego had to complete Water Quality Improvement Plans that showed through modeling a total pollutant load reduction sufficient to meet its water quality goals. It set out to include non-structural BMPs in its model and had some idea how to model some of these programs like irrigation reduction, downspout disconnection, and rain-barrel incentives. Unfortunately, the individual adoption rate of these programs if

voluntary, was not known. However, The WQIP still had a category called “non-modeled, non-structural BMPs” that included education and outreach and other programs dependent on changing human behavior.

The City of San Diego paid a consultant, HDR, Inc., to review the literature (with inadequate documentation unfortunately) and recommend a method to quantify the impact of watershed education and outreach on specific actions of citizens that result in local stormwater pollutant load reduction. HDR approached this the problem as a specific instance of a broader area of research on how problem awareness (education) effects pro-environmental behavior. Under this broader heading many more studies had been conducted from anti-littering to pet waste disposal, to energy conservation, to climate change education activities. With many more studies available, a meta-analysis of multiple studies had been performed to generalize from common determinants of pro-environmental behavior change (Bamberg and Moser 2007, Obaldiston and Schott, 2012). Structured equation modeling was used with these common determinants to apportion effects to each predictor and a range of effects levels for each method of education was determined (HDR, 2014). However, this was as far as HDR was able to break down the predictive use of this method. Because they could not definitively determine the initial pollutant load attributable from each activity that the change in behavior affected or say with any confidence where within the range of effects levels they would be in their particular population with their particular education program, the San Diego plans defaulted to the average of the minimum supportable pollutant removal percentage across all their models (HDR, 2014). This equated to a ten percent reduction in total pollutant load for all constituents modelled. Although this was an unsatisfying final application of the behavioral theories involved, the HDR work provided some guidance on linking loading estimates to meta-analysis models of pro-environmental behavior. After review of the PEB models available, the HDR procedures are explained further.

Quantifying Non-structural BMP Effects on Stormwater Management Pro-Environmental Behaviors

Pro-environmental behavior and its determinants are usually measured through survey instruments. However, a recent review of measurement tools included methods ranging from domain-general and domain-specific self-report measures, field observations conducted with the help of informants, trained observers, or technical devices, to behavioral tasks used in a laboratory setting (Lange and Dewitt 2019). Measurement of a change in behavior would likely make use of the same instruments. In the case of the RCPP, the behavior is a binary adoption or non-adoption of the residential stormwater control measures incentivized by the City (raingardens and cisterns). The endpoint is the installation of this technology on private properties in the target neighborhood. For many other non-structural BMPs, the promoted pro-environmental behaviors result in reduction of an existing pollutant load, or avoidance of a new load in the future. The change toward a new behavior is examined in social science research to understand what goes into making such a decision to change behavior.

A number of theories have been proposed to trace the causal influences of behavior changes in humans. The main categories of theory behind the models of social behavior are self-interest-based theory relying on rational choice such as the Theory of Planned Behavior - TPB (Ajzen 1991) and pro-socially motivated theory like the Norm-Activation Model - NAM (Schwartz 1977). Variants and combinations of these two theoretical constructs have been applied to pro-environmental behavior such as that to be encouraged by non-structural BMPs. The structural path of these two models are shown in Figure 3 for the TPB, and Figure 4 for the NAM. Motivations for self-interest based behaviors encourage people to look for rewards and avoid punishment. This may start with an attitude or intention to adopt a behavior, and a “perceived behavioral control” (PBC) related to the individual’s estimated ability to perform a behavior. Motivations for pro-social behaviors have been associated with conceived moral and social norms, internal attribution, and feelings of guilt. The Values, Beliefs, Norms model shown in Figure 5

focuses more on individual decision-making in selecting pro-environmental behavior based on internalized sense of obligation to act in a certain way or personal norms. Another model of pro-environmental behavior has used social-cognitive theory (Sawitri, Hadiyanto and Hadi 2015). Figure 6 is an example construct for this theory. The “Background factors” of the TPB model or “Person Inputs” and “Background Contextual Affordances” of the Social Cognitive Model may be things that have correlations with geographic and socioeconomic/cultural data that can be developed for the area covered by the watershed model. Still, more local data would be required before developing quantitative relationships.

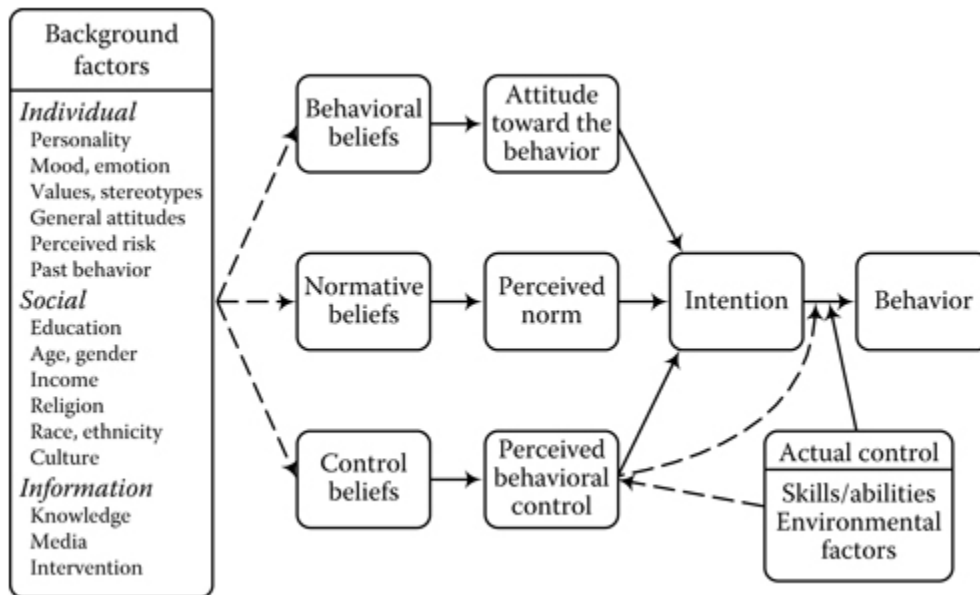


Figure 3. Theory of Planned Behavior

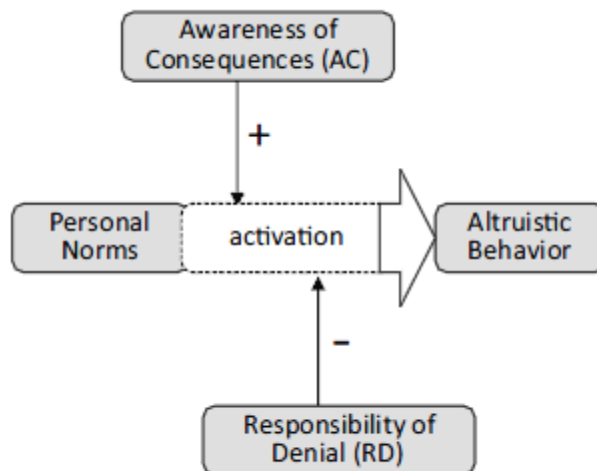


Figure 4. Norm-Activation Model

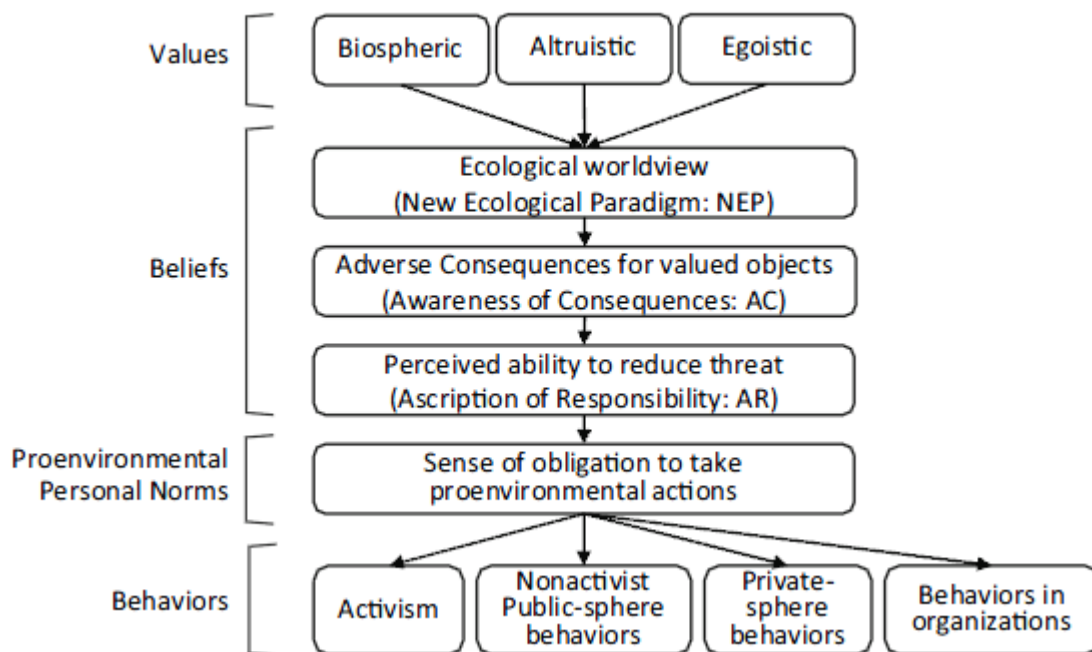


Figure 5. Value, Belief Norm Model

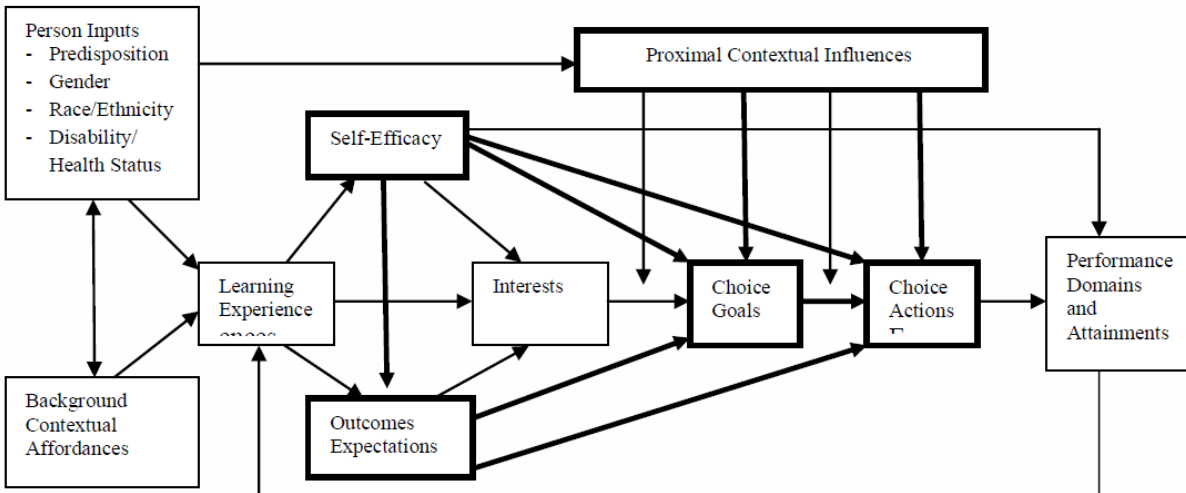


Figure 6. Example of Social Cognitive Theory of Pro-Environmental Behavior

More recently a synthesis of two values-oriented theoretical models (Rokeach's; Schwartz's; Kollmus and Agyeman synthesis) was offered as a predictive alternative (Pavalache-ilie, 2017). Unfortunately, this last effort has also not been applied quantitatively.

These theoretical constructs were not specific to stormwater management and not specific to subdivisions of watershed, neighborhood or municipality. Some used multiple regression analysis with survey instruments to support theoretical relationships. In other cases, meta-analysis with multiple studies and common behavioral or psychological variables were used to assess the validity of a theory of PEB. The sample size in some cases was thought to be large enough and concepts transferable enough to allow some generalization of the resulting model of what leads to pro-environmental behavior. Application of Bamberg-Moser model (Figure 7) has been attempted as a method to determine how much pollutant reduction could result from awareness of the problem through public education by municipal government in San Diego (HDR, Inc. 2014). In this figure, single headed arrows show standardized path coefficients, double headed arrows show correlations and R^2 is the explained variance. Although the correlations in some cases are fairly weak, behavioral "nudges" that target multiple components in the model may increase effectiveness. In addition, combining multi-prong "nudges" in socio-demographic concentrations more susceptible to specific components of the model may also increase effectiveness in that area.

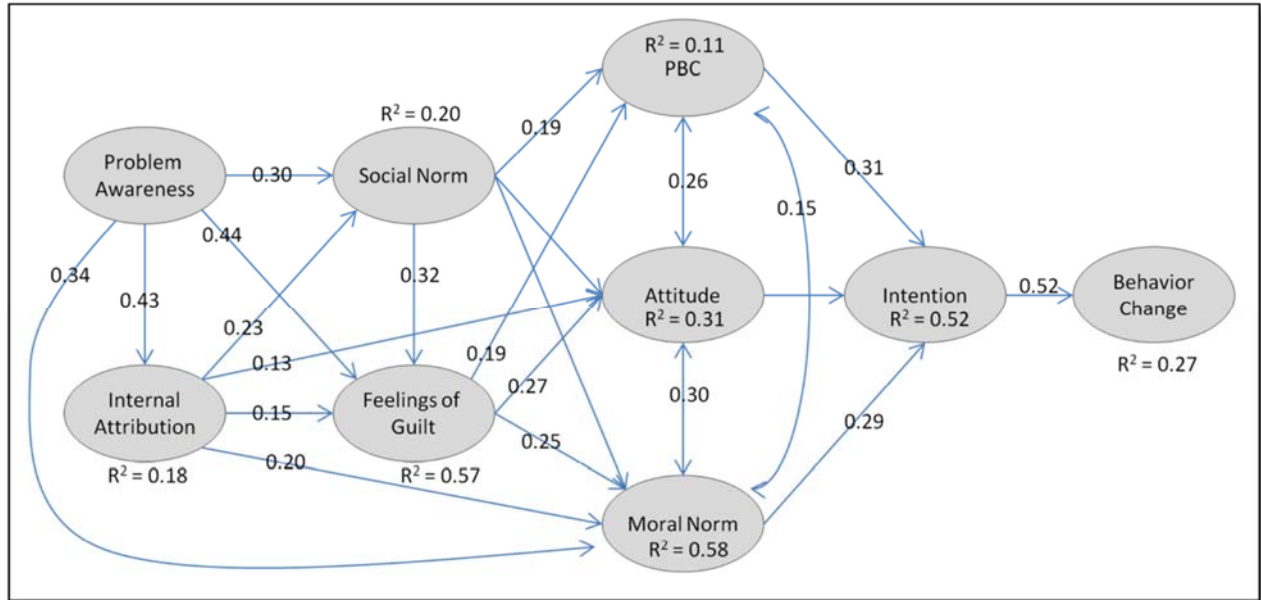


Figure 7. Bamberg and Moser (2007) Meta-Analysis Model of Pro-Environmental Behavior

Another effort combining several of the theoretical approaches above using regression analysis to determine which combination of factors explained more of the results of pro-environmental behavior in water sensitive urban design (WSUD) (Schirmer and Dyer 2018). This study looked more qualitatively at the previous literature and found that factors influencing adoption of pro-environmental behaviors relevant to WSUD fell into four domains: pro-environmental values and norms, awareness and knowledge of environmental problems, proximity and place-based identity, and life-stage and lifestyle factors (Figure 8). Branding this framework, the VAIL (values, awareness, identify, lifestyle) factors, they designed a survey using 22 indicators and tested it on 3,334 residents to determine its utility in understanding adoption of 4 specific pro-environmental behaviors. Regression analysis indicated that the VAIL framework explained significant proportions of the variance in behaviors and suggested ways that these desired behaviors could be increased. Given that there is a theoretical basis to these factors, there may be more predictive power in this empirical model than a simple correlation (Rubin and Baddie 2017).

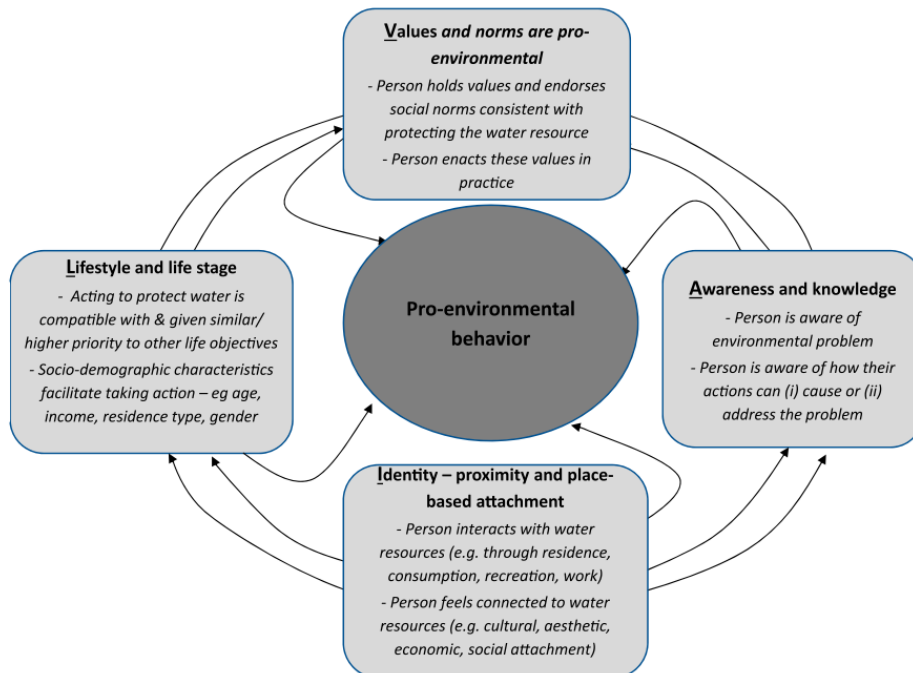


Figure 8. VAIL framework for adoption of pro-environmental behaviors such as WSUDs.

Determinants of Pro-Environmental Watershed Behaviors

For the theories discussed above, research into the drivers or determinants for PEB has included internal, institutional and social factors (Blankenberg and Alhusen 2019). These determinants can be further divided into socio-demographic factors (personal capabilities), attitudinal (psychological factors), habits, and contextual factors (individual, social, and institutional) (Stern 2000). Internal psychological factors include values, beliefs, norms, identity, attitude, awareness, environmental concern, emotions, locus of control and personal responsibility. Habits are considered a unique feedback determinant that has a causal connection to PEB either to reinforce or block such behavior (van der Werff et al. 2014). Contextual factors include social peers, individual influences (connection to nature, place attachment, political ideology), or institutional factors (regulations, government policies, income, degree of collective culture (Blankenberg and Alhusen 2019).

Literature on social variables used in watershed planning can be found at multiple scales and organization methods. Maeda et al. (2018) grouped their study by a physical divide of drainage areas, Brehm et al. (2013) by geographic area, and Turner et al. (2016) by municipal service area. In each case a specific target population was not set out a priori, but information was gathered about demography during surveys. This information was used along with data about participation in stormwater practices to try to match social and demographic characteristics of the population with stormwater practice behavior. Yocum (2014) added public education to the other side of the scale as part of the outcome measure of watershed restoration projects rather than an input to the system to produce quantitative ecological benefits measurable in the stream system itself. Watershed narratives were evaluated in this study as more subjective and descriptive qualitative measurements.

Wu et al. (2015) presented a path analysis that evaluated measurable social, terrestrial, stream hydrology and water quality variables as shown in Figure 9. Three path models based on these relationships not only included the influence of landscape and hydrology on water quality, but also variables like the educational level of residents and home values on water quality outcomes (nitrogen, phosphorus, and conductivity).

If the effectiveness of education is also influenced by the same measurable social variables and these relationships could be quantified empirically, perhaps it could be related to the same instream water quality measures. The problem would be that the resulting coefficients would not be based on physical processes or PEB theory but an equation best fit to existing data. Latent variables such as found in PEB theory could not be separated out and the predictive power would be limited. The biggest problem with this methodology was that while the path analysis allows an assessment of linkages among observable variables, it does not show causation, nor does it allow complete rejection of hypotheses that are not supported by the results (Wu et al 2015).

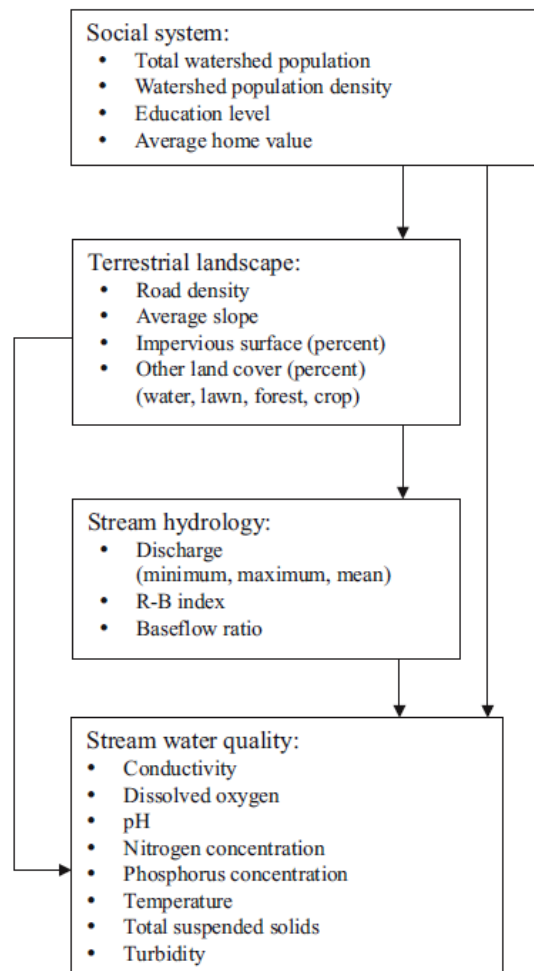


Figure 9. Hypotheses of direct and indirect relationships among social system, terrestrial landscape, stream hydrology, and stream water quality variables (Wu et al. 2015)

Regardless, we hope that using a formal criteria for inferring causality such as outlined in Rubin and Baddie (2017 p. 244) can assist in shoring up the justification for the social factors model selected for our use. This criteria is a weight of evidence approach that requires the following:

- Time sequence – The cause must precede the effect in time.
- Correlation – Changes in the cause are accompanied by changes in the effect
- Ruling out alternative explanations
- Strength of correlation

- Consistency in replication
- Plausibility and coherence

Adherence to this criteria in evaluating behavior models of pro-environmental watershed behavior and its determinants may increase confidence in the quantitative estimates derived from application in the OZ models.

Maeda et al. (2018) primarily provided questionnaire data about BMP implementation and citizen knowledge and included detailed demographic information for two subwatersheds in the Chesapeake Bay area. It could be used as a survey model to produce similar empirical data for Austin. It could also be used as trial data to test the logic in a model of educational material preferences geographically targeted for Austin. Brehm et al. (2013) also provided survey data on factors influencing the adoption of BMPs by residential homeowners including the demographic and knowledge-based factors that may be involved. These may be the variables that need to be reflected in our model that indicates where education should be targeted as a priority and which BMPs would be influenced by a particular education strategy in a particular demographic group. This study surveyed 4 watersheds in Illinois using 2,400 mailed questionnaires as part of the Tailored Design Method to enhance response rates. The BMPs they included in their survey included basic housekeeping such as pet waste disposal but could be broadened to include all areas that environmental education programs may wish to include in the model. In general, the fact remains that when crafting outreach, different types of people respond differently to different types of messages (Schultz 2015).

Unfortunately, the studies most closely resembling what is needed for the OZ project reached unsatisfactory conclusions when it came to the geographic distribution of education as a targeted BMP. The San Diego HDR project that made the most use of the Bamberg and Moser (2007) relationships between education and pro-environmental behavior ended up just applying a single blanket discount factor of 10% to reflect effectiveness of education in pollutant load removal. Bamberg and Moser (2007) updated an older (Hines and Hungerford 1998) meta-analysis of hundreds of surveys matching psychological characteristics or determinants to a variety of pro-environmental behaviors. Although the HDR project was a gray literature application of the Bamberg and Moser model it at least provided a framework for quantifying behavioral non-structural best management practices in terms of pollutant load reduction. The final conclusion may have partially been based on regulatory considerations because results were to be used in the required Water Quality Improvement Plan projects in the San Diego area. The study concluded that the Bamberg and Moser SEM coefficients could justify a range of adoption rates of non-structural measures, but not a value within that range without significant assumptions. In addition, uncertainties about the initial source load and pollutant removal rates of many non-structural controls discouraged the use of these BMPs in a quantitative model even if adoption rates could be determined. However, using adoption rates from pilot studies combined with known pollutant reductions if the behavior was to install a residential structural control would reduce the uncertainties HDR encountered. Further, sociodemographic data could be used to geolocate population concentrations with traits that are susceptible to particular determinants of pro-environmental behavior. It may be possible to then scale the model coefficients to these traits.

The Wu (2015) study went as far as to identify additional levels of education on a broad spectrum of socioeconomic status that was needed for success of phosphorus mitigation because higher educated residents are speculated to be more aware of the environmental problems of lawn fertilizers and pet wastes and be more likely to use low phosphate detergents and dispose of pet wastes properly. This sounded like a highly biased assumption of the author, but two peer reviewed references were provided (Fissore et al., 2011; Lehman, Bell, Doubek and McDonald 2011) in support. However, they were using the level of lifetime educational achievement to predict the effectiveness of a focused short term

environmental public education program; therefore, the conclusion still does not follow directly from the premise.

Turner (2016) is similar to the City of Austin Raincatcher program in that it promoted cisterns and raingardens in a residential neighborhood with subsidized installation. This was a mixed methods case study analyzing the socio-cultural factors that influenced participation including landscaping behaviors, environmental values, attitudes, and perceptions of green infrastructure and stormwater management. Findings included that residents generally disconnected regional and local issues, used perception to guide participation, and used trusted peers more than promotional strategies to determine action. This information could be useful if a similar mixed methods study were conducted in several pilot areas in Austin to determine where context dependent framing and neighborhood partnering would be most needed throughout scale-up of a program.

Important socio-cultural factors influencing participation could also be identified for weighting in our model for geographic targeting of education and in adjusting response rates from more generalized meta-analysis coefficient values of Bamberg and Moser (2007). It is anticipated that multiple formulations of the OZ behavioral model may be needed and it will be an iterative process to maintain a structural theoretical basis while keeping the model parsimonious. If extended to non-structural BMPs beyond education and outreach, program staff should review assumptions for each BMP before completion. The information gained about what behavior change tools would be useful for which BMPs for which specific population and geographic groups could be applied through a framework of community-based social marketing (Schultz 2015).

Model Framework for Behavioral Based Interventions

As seen above, the application of the theories of pro-environmental behavior along with demographic and sociological data becomes complex quickly. A reliable causal structure is needed as well as representation of the agency of the human decision-making process. The use of specific statistical methods helpful in model development are addressed below.

Path analysis

Path analysis is used to exam the structure of relationships among observed variables expressed in a series of equations, similar to multiple regression equations. It is a step up from multiple regression analysis because it can involve relationships among all the variables, not just between independent and dependent variables (Kurusu 2015). However, it is not useful for latent variables that cannot be observed and measured. If the theories of pro-environmental behavior are not considered, path analysis could be used to examine validity of direct and indirect relationships between social and water quality variables using local data. Since the data needed for such an analysis would depend on the scope of the WPD Market Study, it is uncertain if any of the social variables of concern for PEB would be obtained through survey data.

Structural equation modeling

Structural equation modeling (SEM) is similar to path analysis but the relationships examined can be among both observed and latent variables. The use of structural equation modeling in prediction of PEB is seen primarily in meta-analysis combining results from results many individual studies. Development of protocols for systematic reviews and meta-analysis is assisted by using guidance from organizations such as the International Prospective Register of Systematic Reviews (Page et al 2018), the Cochrane Library (Higgins et al. 2019), and the Preferred Reporting Items for Systematic Review and Meta-Analysis (Moher et al. 2009). HDR (2014) applied the SEM coefficients obtained from Bamberg and Moser

(2007) to non-structural BMP effectiveness in San Diego. This supported a range of adoption rates of non-structural measures which were finally reduced to one assumed removal efficiency for all pollutant load removals. Although the ultimate use of the model in watershed modeling was limited, it was a well-documented and encouraging effort. With additional data and judicious assumptions, this appears as a viable alternative to be adapted for use in the OZ project.

Atshan (2018) investigated some causal pathways through which social capital affects environmentally-responsible behavior in Central Texas. Using previous PEB models, a conceptual path model was constructed that considered the impacts of community participation, social trust, and strong relationships on behaviors such as commuting, environmental boycotting, and behavior on Ozone Action Days. The model used environmental concern and internal locus of control as mediating variables between social capital and these environmental behaviors. Structural equation modeling was used to explore associations between social capital and selected PEB (Atshan 2018).

Meta-analysis using SEM has also been used in a variety of ways to determine specific relationships in the study of pro-environmental behavior. Maki et al (2016) found through a meta-analysis of 22 studies that financial incentives can effectively promote both initial change and sustained change of behaviors. Researchers were also able to compare the effects of timing of incentives, cash or non-cash incentives, intervention length, combining financial incentives with other interventions, incentive effectiveness among types of PEBs, and various study designs (Maki et al 2016).

Agent-based modeling

To effectively model the impact of individual behavior on large populations, the existing approach of a reductionist philosophy of science must give way to the science of emergent phenomena (Alberti et al, 2003). This new approach looks to model individual interactions of a population and infer some emergent property of the whole. Agent-based models (ABMs) have become a prevalent approach for modelling these complex systems. ABMs are capable of simulating the decision making and multiple interactions of autonomous agents and between agents and the environment. Complexity in the quantification of non-structural BMP effectiveness makes ABM an attractive method to investigate. Due to the computational needs of ABMs for large, finely segmented geographic areas such as in a distributed watershed model, this approach might be difficult to implement. However, it would allow application of socio-demographic relationships to the determinants in the behavioral SEM such as Bamberg and Moser in an automated calculation to determine adoption rates of non-structural BMPs.

Aguirre and Nyerges (2014) used an ABM to predict participation in sustainability behaviors. The SiMA-C model has also been applied to the social media prompting of environmentally friendly behavior (choice of green energy provider) using an agent-based approach (Alonso-Betanzos et al. 2017). In some cases, the behavior of groups such as residential neighborhoods can be modeled by considering spatial heterogeneity (Chen et al. 2012). Urban economic theory is then used to explain the formation of urban spatial structure resulting from spatially distributed interactions among individual agents.

Rai and Robinson (2015) developed a theoretically-based (TPB – Theory of Planned Behavior) and empirically-driven agent-based model of technology adoption, with an application to residential solar panel systems. Using household-level resolution for demographic, attitudinal, social network, and environmental variables, an integrated ABM model was developed and applied to 9 years of real-world data for a residential solar panel rebate program by Austin Energy. A flowchart of this model structure is shown in Figure 10. Variables included agents' attitudes (sia) and uncertainty regarding those attitudes (U) which are modified through interactions with other agents in their social network through the Relative Agreement (RA) algorithm incorporating TPB and compared to a global threshold (sia_{thresh}). Perceived behavior control beliefs (pbc) regarding ability to afford solar are compared to current payback periods

(PP), which are influenced by house location, electricity prices and available incentives. Adoption of the technology occurs at a timestep (t) when both the attitudinal and the economic criteria are met. The model was run using the readily available Agent Analyst Extension in ESRI ArcGIS software (Johnson 2013).

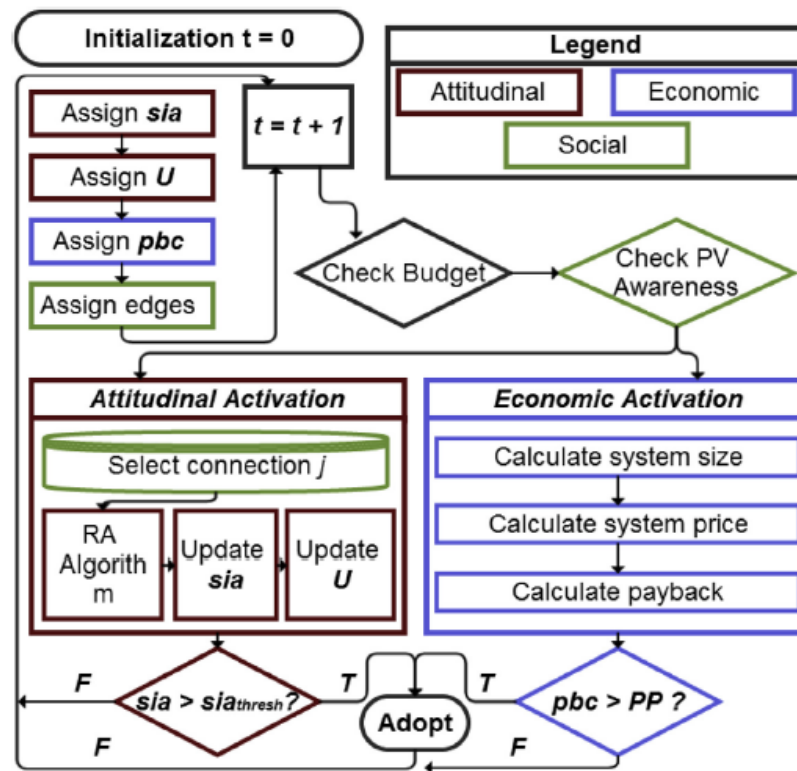


Figure 10. Flowchart describing ABM for solar panel adoption (Rai and Robinson 2015)

A similar model could be formulated for adoption of the RCPP rain garden or cistern technology given WPD and AWU incentives and assistance. A decision algorithm combined with determinants of PEB could be used to predict likelihood of adoption given certain “nudges” tailored geographically across the City. This would take the place of the RA algorithm in the solar panel adoption model in Figure 10. Also, using the software developed for ABM might simplify the daunting accounting and geographic representation of behavioral predictions needed for input at the level of the OZ watershed model spatial grid.

Potential Application of Bamberg and Moser Model to Austin Non-structural BMPs

It is proposed that the OZ project apply the Bamberg and Moser meta-analytical structural equation model based on pooled random-effects correlations within the framework of an agent based model given the socio-demographics geolocated throughout the City of Austin watersheds. The overall structure is shown in Figure 11. The relationships are illustrated by the particular case of the RCPP group behavior “nudge” as it will be scaled to City-wide application. The proposed method incorporates and expands the procedures used by HDR to apply the B-M model to non-structural BMPs in San Diego (HDR 2014).

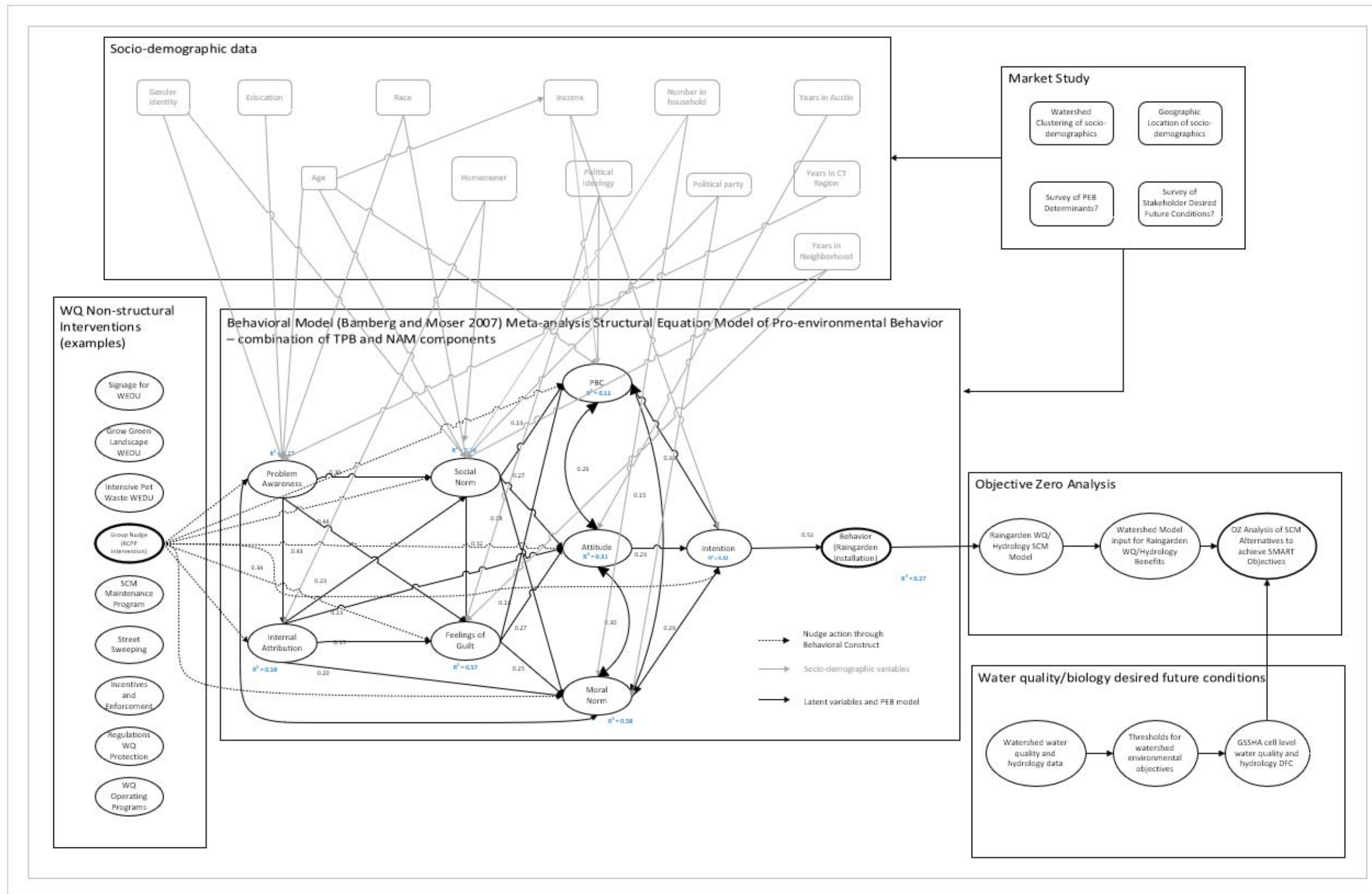


Figure 11. Potential model for OZ non-structural BMPs with RCPP example

The steps used to translate the coefficients from the B-M model to pollutant load reduction were outlined for the Problem Awareness component. In this case, it was assumed that general education and outreach was equivalent to Problem Awareness (HDR 2014). Generalization to the City of Austin case is also discussed.

1. Reformat B-M meta-analysis SEM coefficients to standardized total effects matrix. Interpretation of this matrix: Intention explains 52% of Behavior Change, Problem Awareness explains 43% of Internal Attribution, Problem Awareness explains 18% of Behavior Change, etc. The resulting matrix is shown below:

Construct	Behavior Change	Intention	Moral Norm	Attitude	PBC	Guilt	Social Norm	Attribution	Problem Awareness
Behavior Change	—	.52	.15	.15	.16	.11	.13	.10	.18
Intention		—	.29	.29	.31	.21	.26	.18	.35
Moral norm			—	—	—	.25	.26	.29	.65
Attitude				—	—	.27	.36	.25	.34
PBC					—	.19	.25	.08	.19
Guilt						—	.32	.22	.63
Social norm							—	.23	.40
Internal Attribution								—	.43
Problem Awareness									—

2. Estimate the range of education and outreach effectiveness when combined with each additional model component in promoting the desired behavior change. Potentially, each behavioral non-structural BMP would have its own range of effects depending on which aspects of the PEB model it impacted. In the San Diego case, education was the primary example evaluated. The minimum total effect of 18% was substantiated through a large survey of stormwater BMP adoption rates performed in 2013 by the University of Maryland (Newbern et al 2014, Brehm et al 2013). This was taken as the base correlation between behavior change and education. The combination of education with focus on other specific determinants of PEB were then calculated as follows:

Outreach Method	Calculation	Standardized Total Effect
Education (i.e., Problem Awareness)	$1 - (1 - .18)$.18
Education and Attribution	$1 - ((1 - .18) \times (1 - .10))$.18 to .26
Education and Guilt	$1 - ((1 - .18) \times (1 - .11))$.18 to .27
Education and Social Norm	$1 - ((1 - .18) \times (1 - .13))$.18 to .29
Education and Attitude	$1 - ((1 - .18) \times (1 - .15))$.18 to .30
Education and Moral Norm	$1 - ((1 - .18) \times (1 - .15))$.18 to .30
Education and PBC	$1 - ((1 - .18) \times (1 - .16))$.18 to .31
Education and Intention	$1 - ((1 - .18) \times (1 - .52))$.18 to .61

3. Identify polluting behavior, related pollutants and removal rates. The quantification of pollutant source and reduction is a difficult step for non-structural BMPs. This would have to be documented for each behavioral BMP to be employed by WPD from the list of non-structural BMPs in Appendix A supplied by the WPD Inventory of Potential Solutions (WPD 2015). In the San Diego Case, ranges of removals were compiled from the Center for Watershed Protection literature (CWP 2005, 2008, 2015, 2019). The list of non-structural BMPs and related pollutants for San Diego came from the conditions of their NPDES permit, their WQIP (akin to a TMDL), and Comprehensive Load Reduction Plans for the Telecote and Scripps watersheds (San Diego 2012). The relative source of

pollutants was attributed to Pollutant Generating Activities (PGA) targeted within each Pollutant Source Characterization (PSC) land uses mapped for the watersheds. Pollutant reduction strategies in these documents were categorized for each pollutant as either **primary**, **secondary**, or **not addressed**. Removal potential addressed by each of the BMPs was evaluated as being **major**, **moderate**, **minor** or **no removal** for each pollutant. Load reductions for each pollutant were categorized for each BMP as 90% for **primary**, 60% or 30% for **secondary** (depending on whether they were **moderate** or **minor** removal for that pollutant), and 0% for **not addressed**. Loadings for each pollutant were also classified as **Entirely** (100%), **Largely** (66%) or **Partially** (33%) the consequence of the polluting behavior that each of the BMPs addressed. Although this system seemed to be primarily based on “additional literature review of the CWP Manuals and engineering judgement” it was at least well documented (HDR 2014). The resulting matrix of pollutant removal potential and pollutant consequences by % reduction is show below:

Pollutant Removal Type	Entirely (100%)	Largely (66%)	Partially (33%)
Major (90%)	90.0%	59.4%	29.7%
Moderate (60%)	60.0%	39.6%	19.8%
Minor (30%)	30.0%	19.8%	9.9%

- Calculate matrix of impacts from each non-structural BMP for each PEB determinant. Reduce the table above to impact matrices for each BMP. This uses the range of total standardized effect for all the determinant combinations affected by the BMP. When education is considered alone as represented by problem awareness, this is relatively simple. In the San Diego case, the table below was calculated using the base factor of 18% education effect on behavior. For other BMPs that may include Education combined with a message targeted to one or more of the PEB determinants, things become complicated quickly and ranges of effectiveness must be reported.

Pollutant Removal Type	Entirely (100%)	Largely (66%)	Partially (33%)	Factor	Entirely (100%)	Largely (66%)	Partially (33%)
Major (90%)	90.0%	59.4%	29.7%	x .18	16.2%	10.7%	5.3%
Moderate (60%)	60.0%	39.6%	19.8%		10.8%	7.1%	3.6%
Minor (30%)	30.0%	19.8%	9.9%		5.4%	3.6%	1.8%

- Estimate impacts of programs entirely under City control. The table above is recalculated for municipal operations using a factor of 80% as a conservative estimate of translating a city directive carried out by city staff in making a behavior change. It also represents the maximum rate of behavior change that could be expected by education and outreach alone. The previous categorizations of each non-structural control as major, moderate, or minor load reductions and the behavior addressed by the BMP as entirely, largely, or partially responsible for the loading of each pollutant are used to arrive at the upper range of impact of each non-structural BMP that is part of municipal operations or otherwise controlled by the City. In the San Diego project, this was also used as the upper end of effectiveness for all non-structural BMPs even if not under City control.

Pollutant Removal Type	Entirely (100%)	Largely (66%)	Partially (33%)	Factor	Entirely (100%)	Largely (66%)	Partially (33%)
Major (90%)	90.0%	59.4%	29.7%	x .80	72.0%	47.5%	23.8%
Moderate (60%)	60.0%	39.6%	19.8%		48.0%	31.7%	15.8%
Minor (30%)	30.0%	19.8%	9.9%		24.0%	15.8%	7.9%

6. Apply matrices of effectiveness to each BMP for each PEB and for each pollutant. HDR presented results for three non-structural BMPs for the problem awareness PEB alone. For the minimum, the 18% effectiveness rate was assumed, and 80% for the maximum shown in the next three tables.

Nonstructural Strategy	Bacteria	Metals	Organics	Sediment	Pesticides	Nutrients	Oil and Grease	Dissolved Minerals	Trash	Consequence
Procedures for Swimming Pool Discharge	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	16.2%	0.0%	Entirely
Pet Waste Pick Up	10.7%	0.0%	0.0%	0.0%	0.0%	7.1%	0.0%	0.0%	0.0%	Largely
Outreach for Over Irrigation	1.8%	1.8%	1.8%	1.8%	5.3%	5.3%	1.8%	1.8%	1.8%	Partially

Nonstructural Strategy	Bacteria	Metals	Organics	Sediment	Pesticides	Nutrients	Oil and Grease	Dissolved Minerals	Trash	Consequence
Procedures for Swimming Pool Discharge	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	72.0%	0.0%	Entirely
Pet Waste Pick Up	47.5%	0.0%	0.0%	0.0%	0.0%	31.7%	0.0%	0.0%	0.0%	Largely
Outreach for Over Irrigation	7.9%	7.9%	7.9%	7.9%	23.8%	23.8%	7.9%	7.9%	7.9%	Partially

Nonstructural Strategy	Bacteria		Metals		Organics		Sediment		Pesticides		Nutrients		Oil and Grease		Dissolved Minerals		Trash	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Procedures for Swimming Pool Discharge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.2	72.0	0.0	0.0
Pet Waste Pick Up	10.7	47.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	31.7	0.0	0.0	0.0	0.0	0.0	0.0
Outreach for Over Irrigation	1.8	7.9	1.8	7.9	1.8	7.9	1.8	7.9	5.3	23.8	5.3	23.8	1.8	7.9	1.8	7.9	1.8	7.9

Note: Values shown are percentages.

7. Determine the fraction of total pollutant load entering the watershed that is generated by behavior that the BMP addresses. This is the point where HDR determined that insufficient information was available to assume these fractions. Instead, they took the average pollutant removal of all BMPs using low removals for public awareness only BMPs and high removal rates for BMPs under municipal control. HDR then averaged these averages across pollutants and used this value (10.1% reduction) for the combined effect of all non-structural BMPs. They also listed the limitations of this approach including:

- Lack of geospatial variance represented that would occur depending on where the activities to be impacted take place,
- Lower average values for load reduction that would occur for BMPs that are out of city control and do not target additional determinants of PEB,
- Higher average values that would occur for BMPs that target one or more determinants of PEB,
- Lack of field studies correlating behavior change to actual measured change in pollutant loads,
- Data for the behavioral coefficients based on surveys is actually better than data for the estimated load reductions based on categorizations for removal type and consequence.

Many of these limitations could be reduced through employing an agent-based model for non-structural BMPs with a behavioral component. Also, determining correlations between PEB determinants and geolocated socio-demographic data could be used to help predict load generating behavior and behavior changes from non-structural BMPs. If this could be applied on the same spatial grid as the GSSHA model, then the load reductions from any combination of non-structural BMPs could be determined. Although this is a complicated project, that is the domain where agent-based models are most beneficial. When determining the aggregate impact of complex individual behavior changes on water quality is required, an agent-based model framework may be the only method of simulation available that would correspond to the distributed hydrologic and water quality models to be used for the OZ project.

Population of Interest

The population to be represented by the OZ project would be that living on the watershed area of the City of Austin ETJ and extending beyond those boundaries to the headwaters of the watersheds of Barton and Onion Creek and the boundaries of adjacent watersheds surrounding the ETJ. The time unit of analysis would be a long-range planning horizon of 50-100 years. Since the incremental time unit of analysis is driven more by the hydrology it may be as short as a few minutes for rainfall and streamflow data. For purposes of long-term planning, the social components of the model will be driven more by life stage and life span statistics if this level of detail is called for. The spatial unit of analysis will be determined by the watershed model selected for the project. Currently, the US Army Corps of Engineers GSSHA model is being used for the OZ project hydrology. Groundwater components may require some modification to the base models or integration with an appropriate karst aquifer model. Water quality constituents may be evaluated using a statistical model or a water quality model that can accept the distributed hydrology from the GSSHA and groundwater models.

Units of social and geographic analysis would be individuals and/or living units associated with a parcel of land. Variables within the population will be characteristics of that parcel and individuals that affect the pollutants generated and the potential to change behavior based on public education and outreach and other non-structural BMPs. These would include basic demographics, economic information, ethnicity, race, residing adults, children, age makeup, education, etc. Parcel data would include impervious cover, floor area, land cost, dwelling cost, landscaping, drainage features, etc. The pollutants reduced based on changed behavior would also be variables, although their generation may be generalized to behaviors, not individuals. A sampling frame for demographics could be census lists for the entire City, or the list of residents or residences within a pilot area. If the initial scope is small enough, demographic data can be collected along with other survey data. Characteristic behavioral and opinion descriptors of the population would be obtained through survey data to determine if they can be correlated to any socioeconomic, cultural, or geographic data. Such correlations could be used to geo-locate the varied environmental and water quality desires of citizens/stakeholders across the city landscape. One consideration of the OZ

project was to define water quality objectives that would be “relevant” to stakeholders. Residents may have different desired future conditions for their local streams than they have for City-wide resources like Lake Austin, Barton Creek or Barton Springs, for example. Therefore, geo-locating desired future conditions may require a proximity factor. In addition, the exact use of stakeholder desired future conditions has yet to be determined in the OZ framework. Direction from those citizens residing in a watershed has to be balanced with ecological value of the resource, City strategic goals found in IMAGINE Austin or Strategic Direction 2023, and equity considerations across the City.

For sampling data collection assuming questionnaires will be developed, a pilot study area will naturally be initially tested for this study. In addition, a sub-program of the City of Austin Watershed Education and Outreach Program could be used as a starting point along with a targeted area of study. This population will be the Waller 3 Sub-basin area, the focus of the RCPP shown in Figure 12 below.

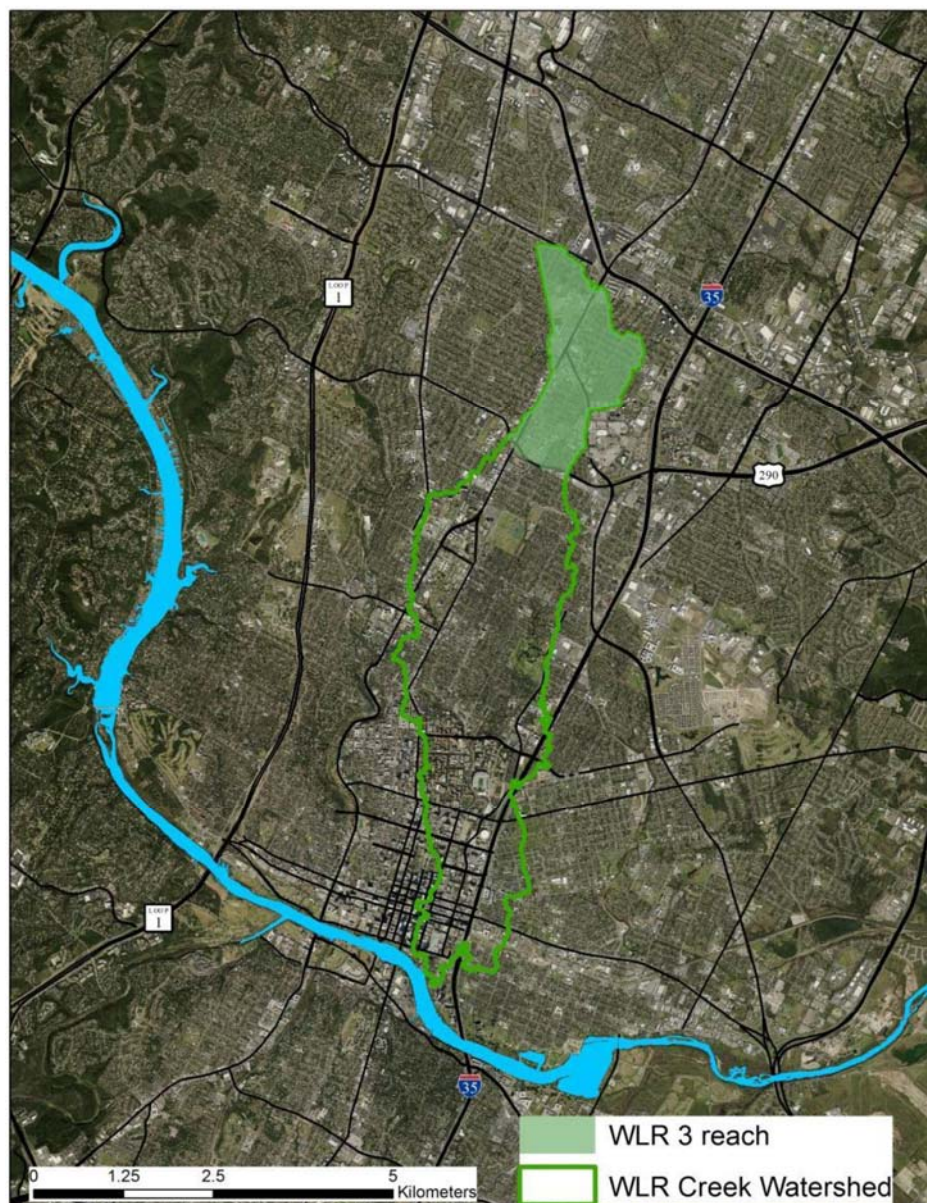


Figure 12. Location of Waller Creek and the Waller 3 Reach in the City of Austin, Texas.

Even within this reach, the area may be too large to canvas adequately, and a subarea may be subsequently selected for survey. Design of the questionnaire will be made with direction from survey consultants available through City contract in order to avoid bias and assumptions that may reduce its value. This pilot effort will be primarily for methodology and instrument testing. The City is such a diverse landscape both physiographically and socially that this small area does not serve as a representative microcosm of the entire population. It is not a vulnerable population although representatives of some of the vulnerable populations in Austin such as the disabled or elderly may reside there. If homeless citizens are semi-permanent residents of the subwatershed surveyed they could be asked for information while onsite, but there is no guarantee that they will be found. Demographic data on the questionnaires may provide information to determine if residents are members of vulnerable populations. Results of questionnaires will be confidential, so disclosure of any personal information such as belonging to a vulnerable population should not bring harm to any participant in the study. Participation in questionnaires and inclusion of residences' property as a modeled parcel is not considered inherently harmful, but subsequent uses of model results will be reviewed and considered for their potential harmful ramifications for participants including property values, social stigma, or bias/discrimination issues before completion of the project and release of any results.

Equity

The City is currently developing a methodology to include racial equity in determining the selection of projects, programs, and regulatory changes. WPD has been one of the first departments to begin development of this Equity Assessment Tool (WPD Equity Team 2019). When implemented, the tool will assist WPD in:

- Focusing on human centered design and building institutional empathy;
- Engaging residents in decision-making processes, prioritizing those adversely affected by current conditions;
- Bringing conscious attention to racial inequities and unintended consequences before decisions are made;
- Advancing opportunities for the improvement of outcomes for historically marginalized communities;
- Removing barriers to the improvement of outcomes for historically marginalized communities; and
- Affirming our commitment to equity, inclusion, and diversity.

Because the OZ project SMART objectives are intended to be relevant to the self-reported needs of the residents in each watershed and their desired future conditions for their local water resources, equity will be a factor considered in objectives development. Environmental attitudes and opinions, especially those related to local water quality, will be coded from interviews along with socioeconomic status from survey data to ensure that needs of disadvantaged groups and communities will be validated in the OZ objectives. The natural east-west watershed physiography divide coinciding with the historical racial and environmental protection divide of the City will be a considered in formulating OZ objectives. Coordination with the Equity Team of WPD will likely be formalized in the final or amended OZ project workplan (Porrás 2019) and through ERM Division management.

The determinants of pro-environmental behavior to be used in modeling should include terms that promote equity. Project, regulation, and program selection should include equity functions to promote outcomes geographically that reflect underserved communities of color needs over historically advantaged western watersheds while maintaining the objective science-based origin of the OZ project. This can be done through engagement in determining the needs of residents for desired future conditions

of their nearby watersheds and creeks and regional resources. Determining the current local uses and future conditions desired by neighborhoods for water quality, flood control, and erosion control as represented in the cross section, substrate, bank condition, morphology, flow permanence, baseflow, biological health, and aesthetics of the waterbodies they frequently visit and use is needed to make the OZ objectives socially relevant.

The WPD Equity Assessment (Equity Team 2018) indicated several improvements that should be made to the department project prioritization system. These improvements would also apply to the OZ project. Using race as one of the determinants of pro-environmental behavior in modeling non-structural BMPs may reduce the level of risk due to reliance on technical environmental data and help consider the variable impacts these risks may have on vulnerable communities.

The incorporation of social attributes in the OZ project is one opportunity to incorporate community specific data to acknowledge and represent disparate outcomes based on vulnerability. Correlation of survey data with existing data for the Social Vulnerability Index (SVI) (Flannigan et al 2011) from the CDC by census tracts might be used to explain variations of pro-environmental behavior not explained by race alone. Variables and themes in the SVI database are shown in Figure 13. Additional efforts to consider current neighborhood makeup and desired conditions might be similar to those suggested for redevelopment planning in Austin (Mueller and Dooling 2011). Additional data concerning attitudes and desired future conditions related to social equity that would alter relevant water quality objectives geographically across the City may be possible to obtain through the proposed Market Study. Alternative methods to validate objective statements with stakeholders to ensure social relevance may be developed in the OZ workplan (Porrás 2019)

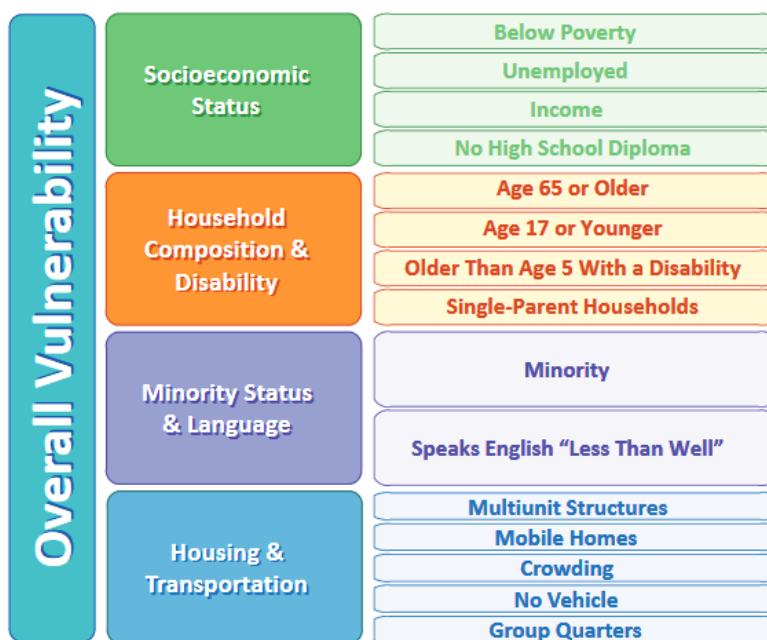


Figure 13. Variables and Themes Included in the CDC Social Vulnerability Index.

Data Management and Analysis

The information gathered from U.S. Census Blocks will be downloaded from the internet in spreadsheet format or GIS coverages. Data will be converted and maintained in ArcGIS. Similarly, the TCAD, WCAD and HCAD tax parcel data will be downloaded using the county tax assessors' parcel identification system. The minimum variables expected from these sources will be described in a Quality Assurance Project Plan (QAPP) for the project. Social survey variables will be collected by questionnaire that may be administered over the internet, at gatherings, filled out on paper manually, or over the phone. Internet survey data may be collected through the City's web site and downloaded to spreadsheets for storage. Survey data collected through other means will be transferred to similar spreadsheets. Geolocated data from surveys will be converted and maintained in ArcGIS.

It is anticipated that questionnaire data will characterize the social attitudes, values, and tendencies of the respondents that may correlate to the determinants of pro-environmental behavior. Similarly, socio-economic and land parcel data will also be considered independently for their correlations to these determinants (residence will tie the respondents to location). The PEB determinants themselves are evaluated directly through a subset of questions as to the degree of influence by social norms, moral norms, feelings, of guilt, perceived behavioral control, etc. Additional data may be available from interviews conducted with the RCPP project or Market Study. These data may be coded for keywords and evaluated quantitatively or used to interpret survey data.

The meta-analysis of pro-environmental behavior by Bamberg and Moser (2007) provided relationships based on a combination of the Theory of Planned Behavior (TPB) and Norm- Activation Model (NAM). This is the center Structural Equation Model (SEM) diagram on Figure 11 including path-coefficients, correlations, and explained variances. Documentation of how the determinants were coded in the individual experiments may not be available because the meta-analysis only used the effects levels and pooled correlation matrix. The correlation matrices of the census data, questionnaire data, and tax parcel data may be calculated in STATISTICA, R, or SAS software. It is planned to use results of structural equation modeling in causal analysis to determine the relationships between the social characteristics, socio-economic, and parcel variables and the determinants of pro-environmental behavior. The relationship between determinants from meta-analysis such the Bamberg and Moser model can then be used as the kernel decision function for PEB (in this case individual adoption of non-structural BMPs) since ABMs provide the ability to specify rules-based algorithms that mimic cognitive and social processes of human decision making. The ABM could be constructed through the ESRI Agent-Analyst extension to ArcGIS (Johnson 2013), NetLogo (Wilensky 1999), MASON (Luke et al 2005), Repast (REcursive Porous Agent Simulation Toolkit) (North et al 2013) or one of several ABM software toolkits currently available (Abar et al 2017).

Conclusions and Implications

Anticipated Findings

If there are strong correlations between survey data and the Bamberg and Moser model components, it could be adapted as a method for estimating non-structural BMP adoption based on voluntary programs stimulated by public education and outreach. Each of the programs could have an *a priori* profile that could be adapted for preferential appeals to parts of the population. This profile may need to be determined through a group process including the program implementation staff. If this can be expressed in ranges of the social variables, then the program effectiveness can be predicted through the correlation of social with pro-environmental determinant variables. Therefore, each cell of a watershed model would

be variably “susceptible” to a voluntary non-structural BMP or outreach program based on its social variable makeup.

Each outreach program would also have an endpoint result whether it reduces a polluting behavior, increases a restoration behavior, or promotes installation of a specific control device. For example, the RCPP project has an endpoint result of adoption or non-adoption of cisterns or raingardens on private lots through the City incentive program. The impact of each of these cisterns or raingardens would be a known quantity assuming they meet City design criteria and are installed, operated and maintained properly. The numerical values for these results profiles in terms of units of measure within the model cells and per individual person or unit area of land would need to be worked out for generalization. The distributed water quality model could then be used to target the non-structural BMPs such as outreach to the residents and water quality problem prevalent in the area of interest. Combined with opportunities for structural BMPs, the model could incorporate an iterative optimization routine to maximize the achievement of OZ objectives at a reasonable cost in a reasonable timeframe using a customized watershed plan.

Implications

Practical implications would be to provide WPD services where they were needed and could do the most good towards desired OZ objectives for the least amount of City money in a reasonable timeframe including steering services to vulnerable areas of the City to further equity goals. Research implications would include providing valuable baseline data about environmental attitudes specific to watershed issues in the City for future comparison as the community changes. This survey data could also be used along with outcome measurements to assess how well these services are meeting the community needs. Policy implications would be that our models that usually only include physical processes of hydrology, hydraulics, climate, chemistry, and biology would now have a social element. This would help focus policy and services on the people living on the watershed in addition to the necessary focus on the physical/chemical/biological characteristics of the watershed. Theory implications would be the practical application of a pro-environmental behavior model based on both NAM and TPB theory.

Limitations

Methodology

In determining the reduction of pollutant producing behaviors, the problem in past studies is that we may not know with any certainty the percent reduction in pollutant load that a behavior change will bring and/or we do not know the total pollutant loading produced from the current/past behavior to begin with. For example, it may be possible to predict a certain percentage reduction in people dumping their oil down the storm sewer resulting from outreach. However, estimation of pre- and post-treatment impacts on oil pollution discharged to the receiving water may be uncertain. This may lead to a water quality model unable to evaluate alternatives to meet OZ objectives. However, the proposed methodology has flexibility for exploration and will also provide an initial basis to quantify the problem and provide a consistent approach across all non-structural BMPs.

Sample

We do not currently know if the survey sample size and coverage will characterize the watershed population at the resolution of the cell size used in the hydrological/water quality model. We will also have to geolocate and perform some kriging or smoothing to get complete coverage for all necessary model variables for the entire watershed areas for each cell. Also, many peripheral and interior areas are not entirely or even partially in the City jurisdiction yet contribute pollutant loading to Austin streams. In

addition, both the RCPP phases and the Citywide Market Study have limited budget and timeframe for completion. This may restrict their utility in gathering the optimal sample size for non-structural BMP additions to the OZ modeling project. City and contract staff are currently developing questionnaires for the RCPP project and data collection for the Market Study will be coordinated with the contractor selected for this project. Hopefully sample size, variables surveyed, and other considerations can be negotiated to meet requirements of the OZ project as well as the Market Study scope. However, the number of questions may not be sufficient to define each of the determinants of pro-environmental behavior for the model.

Summary and Next Steps

Quantifying non-structural BMP benefits comparably to structural BMPs is desirable in fiscally responsible planning for a municipal non-point source pollution control strategy. In order to get the optimum benefits out of their budget, a municipality needs to distribute funds in a manner to programs and capital projects proportionately in areas where they will best benefit the environment and meet citizen desires for their water quality resources. There are questions of equity, environmental justice, as well as efficacy of education and outreach in different socioeconomic and cultural situations that should be considered quantitatively. Bringing theory and data together across different disciplines and developing a supportable methodology covering all non-structural BMPs in a municipality has not been accomplished based on this literature review.

Previous efforts typically stopped when reaching the point where they could not parse monitored or modeled pollutant loadings to polluting behaviors adequately. However, in virtually every regulatory guidance, industry project and research literature on the subject, it was said that a model of non-structural best management practices was needed, and more data should be collected. Currently, a comprehensive model of non-structural control effectiveness does not seem to be under investigation, and collection of relevant data is not forthcoming. It seems to be left to social science researchers to kick-start the effort. Relaxing the expectations for certainty in a model of human behavior and using what theories can be applied to pro-environmental behavior change would be the first recommendation for engineers seeking to incorporate non-structural BMPs into their watershed models. Applying a statistical model for tying community characteristics to polluting behaviors and the most effective non-structural BMP practices would be another recommendation. Finally, given the range of these practices, some creativity will be needed to adequately parse pollutant loads well enough to test the model. Group decision making methods with knowledgeable staff and outside experts may be needed where data is absent.

The next steps in WPD development of an appropriate agent-based NSBMP model for the OZ project are proposed below in Table 2. Depending on funding and prioritization, a workplan for completion will be prepared and initiated during FY 20/21. The workplan will dovetail into the Objective Zero Workplan (Porrás 2019). The OZ workplan describes the two path process by which these water quality objectives are determined and proposed use in implementing water quality BMPs. One path in the process will examine relevant ecological thresholds using data analyses linking ecology with water quality and hydrology. Another path consists of building and running watershed models to define the current status of every Austin waterways. From those models, various future conditions can be simulated for different BMP strategies and then be compared to desired future conditions based on the relevant ecological thresholds.

Table 2

Proposed steps in incorporating NSBMP into OZ Modeling for BMP Implementation Plan.

1. Determine if questionnaires and surveys for the RCPP and Market Study can be modified to incorporate data gathering on social variables and determinants of pro-environmental behavior.
2. Geographically locate socioeconomic data and survey responses to form response profiles over the planning area watersheds. Include a measure of Desired Future Conditions for water quality based on Market Survey and .
3. Conduct regression analyses between social variables and determinants of pro-environmental behavior responses.
4. Evaluate results in coordination with WPD Equity Team and City Demographer.
5. Determine functions for domain-specific baseline loadings that can be acted on by NSBMPs from literature sources and partitioning of GSSHA hydrology and NPS generated loadings by land use types.
6. Develop and test method of incorporating NSBMP functions into GSSHA and NPS models to be used in the OZ project.
7. For each NSBMP in Appendix A, determine behavioral response function for agents depending on social profile based on regression analysis and determinants of PEB from B-M SEM model.
8. Incorporate behavioral response functions for adoption of PEB, domain-specific loadings, response per unit of NSBMPs on these loadings and hydrology, and cost of NSBMPs into selected agent-based modeling software assuming OZ model grid cell size in geographic resolution.
9. Document assumptions in agent-based model and review with Equity Team and City Demographer.
10. Obtain social profile dependent adoption rates and impact of NSBMPs across planning area from linking agent-base model simulations to OZ GSSHA and NPS models in terms of hydrologic and water quality indicators selected as objective measures.
11. Use implementation of NSBMPs alongside opportunities for structural BMPs in OZ optimization to determine best mixture scenario to achieve water quality and hydrologic objectives in target timeframe and calculate resulting program, regulatory, and capital costs for WPD.
12. Iterate around cost and target timeframe limitations to determine proposed BMP implementation plan across City watersheds that will result in the achievement of water quality objectives within reasonable target planning timeframe within projected WPD budgetary constraints.

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Masterplan Solutions - WPD Masterplan Update 2015/2016 (8/19/2016) - Inventory of Potential Solutions (12/15/2015)	Flood	Erosion	Water Quality	Integrated	Non-structural	Structural	Program Regulatory	Capital	Point Line Area	Public Private Partnership	Voluntary Mandatory City - Advisory	Development/regulatory Permitting/enforcement Pollution prevention Strategic planning/mgmt Education/outreach Incentive /adoption Awareness/ adoption Probabilistic Landuse-specific Designers/engineers Rural land owners Programmatic Co-benefits/spillover	Single Behavior Repeated Behavior Install and Maintenance	Bacteria Metals Organics Sediment Pesticides Nutrients Oil and Grease Dissolved Solids Trash	Source	Peak Flow Reduction	Volume Reduction	Habitat Restoration/Creation	Aquatic Life	Source																															
	Mission			Type	Method		Mode		Funding		Participation		Taylor/Fletcher 2007				Behavior Modification Category				Repeatability		Pollutants										Hydrologic Impact																		
b. Control of Livestock in Riparian Areas (p. 178)			✓	✓		✓			✓	✓		✓					✓		●	○	○	●	○	○	○	○	○	○	○	HDR - Animal Related	○	○	○	○	HDR - Animal Related																
c. Specialized Grazing Systems (p. 178)			✓	✓		✓			✓			✓					✓		●	○	○	●	○	○	○	○	○	○	○	HDR - Animal Related	○	○	○	○	HDR - Animal Related																
44. Riparian Restoration (p. 178)			✓	✓					✓	✓	✓	✓		✓			✓		○	○	○	●	○	○	○	○	○	○	○	TT-CLRP Chollas 5.1	○	○	●	●	TT-CLRP Chollas 5.1																
VIII. Water Quality Operating Programs (p. 187)																																																			
45. Intergovernmental Compliance (p. 187)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	○	○	○	○	○	○	○	○	○	○	○	○	HDR - Risk Assessment	○	○	○	○	HDR - Risk Assessment															
46. Surfacewater Evaluation (p. 187)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	○	○	○	○	○	○	○	○	○	○	○	HDR - Risk Assessment	○	○	○	○	HDR - Risk Assessment																
47. Groundwater Evaluation (p. 188)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Risk Assessment	○	○	○	○	HDR - Risk Assessment																
48. Endangered Salamander Protection (p. 188)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Risk Assessment	○	○	○	○	HDR - Risk Assessment																
49. Watershed Modeling and Analysis (p. 189)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Risk Assessment	○	○	○	○	HDR - Risk Assessment																
50. Stormwater Quality Evaluation (p. 189)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Risk Assessment	○	○	○	○	HDR - Risk Assessment																
51. Stormwater Treatment (p. 190)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Risk Assessment	○	○	○	○	HDR - Risk Assessment																
52. Watershed Education (p. 190)			✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	○	○	●	○	●	●	○	○	○	○	○	○	Roll-up					Roll-up															
a. NPS Pollutant education campaigns and initiatives (p.190)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Regional Education	○	○	○	○	HDR - Regional Education																
b. Citywide Integrated Pest Management program (IPM) (p.190)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	●	○	●	●	○	○	○	○	○	HDR - Pesticides/Herbicides	○	○	○	●	HDR - Pesticides/Herbicides																
c. Earth Camp for Elementary Students (p.190)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Regional Education	○	○	○	○	HDR - Regional Education																
d. Grow Green Landscape program (p.190)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Regional Education	○	○	○	●	HDR - Regional Education																
e. Green City initiative (p.190)			✓	✓		✓			✓	✓	✓		✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Regional Education	○	○	○	○	HDR - Regional Education																
f. Clean Creek Campus (p.190)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Regional Education	○	○	○	○	HDR - Regional Education																
g. Keep Austin Beautiful (KAB) creek cleanup coordination (p.190)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - Regional Education	○	○	○	○	HDR - Regional Education																
h. Scoop the Poop (p.190)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		●	○	○	○	○	○	○	○	○	○	○	HDR - Pet Waste	○	○	○	○	HDR - Pet Waste																
i. Signage for watershed education (p.190)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	BPJ	○	○	○	○	BPJ																
53. Stormwater Compliance (p. 190)			✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - PGA Inspection/ Education	○	○	○	○	HDR - PGA Inspection/ Education																
54. Water Quality Planning (p. 192)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ																
55. Barton Springs Operating Permit (p. 192)			✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓		○	●	●	●	●	●	○	○	○	○	○	BPJ	○	○	●	●	BPJ																
56. Underground Storage Tanks (p. 192)			✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓		○	○	●	○	○	○	●	○	○	○	○	BPJ	○	○	○	●	BPJ																
57. Lady Bird Maintenance (p. 193)			✓	✓		✓			✓	✓	✓		✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	BPJ	○	○	●	●	BPJ																
58. Environmental Policy (p. 194)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ																
IX. Water Quality Regulations (p. 212)																																																			
59. Pollution Prohibition (p. 212)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	●	●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ															
60. Litter and Sanitation Laws (p. 213)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	●	●	●	●	●	●	○	●	○	○	BPJ	○	○	●	●	BPJ																
61. Animal Regulations (p. 213)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		●	○	○	●	●	●	○	○	○	○	○	HDR - Animal -related BMPs	○	○	○	○	HDR - Animal -related BMPs																
62. Municipal Solid Waste (p. 213)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	●	●	●	●	●	●	○	●	○	○	BPJ	○	○	●	●	BPJ																
63. Fertilizer, Integrated Pest Management, and Landscaping Standards (p. 214)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	●	○	●	●	○	○	○	○	○	HDR - Pesticides/Herbicides	○	○	○	●	HDR - Pesticides/Herbicides																
64. Turf and Landscaping Regulations (p. 214)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	●	○	●	●	○	○	○	○	○	HDR - Pesticides/Herbicides	○	○	○	●	HDR - Pesticides/Herbicides																
65. Street Sweeping (p. 215)			✓	✓		✓			✓	✓		✓	✓	✓	✓		✓		○	●	○	●	○	●	○	○	○	○	○	HDR - Street Sweeping	○	○	○	○	HDR - Street Sweepong																
66. Industrial Storm Sewer Discharge Permits (p. 215)			✓	✓		✓			✓	✓		✓	✓	✓	✓		✓		●	●	●	●	●	●	●	○	○	○	○	BPJ	○	○	○	○	BPJ																
67. Hazardous Materials (p. 215)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	○	○	○	○	BPJ	○	○	○	○	BPJ																
a. Hazardous Material Storage and Spill Control (p. 215)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	○	○	○	○	BPJ	○	○	○	○	BPJ																
b. Hazardous Material Traps (p. 216)			✓	✓		✓			✓	✓	✓						✓		●	●	●	●	●	●	●	○	○	○	○	BPJ	○	○	○	○	BPJ																
c. Remediation Cleanup Standards (p. 216)			✓	✓		✓			✓	✓	✓						✓		●	●	●	●	●	●	○	○	○	○	BPJ	○	○	○	○	BPJ																	
68. Wastewater Regulations (p. 216)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	●	○	○	○	○	○	○	○	HDR - WW leaks/infiltration	○	○	○	○	HDR - WW leaks/infiltration																
a. Wastewater Service Extension Requests (SERs) (p. 216)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - WW leaks/infiltration	○	○	○	○	HDR - WW leaks/infiltration																
b. Wastewater Line Construction (p. 217)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	TT-CLRP Chollas 4.7	○	○	○	○	TT-CLRP Chollas 4.7																
c. On-Site Sewage Facility Requirements (p. 217)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	HDR - OSSF	○	○	○	○	HDR - OSSF																
d. Phosphorous Controls (p. 217)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		○	○	○	○	○	○	○	○	○	○	○	BPJ	○	○	○	○	BPJ																
69. Water Quality Controls (p. 218)			✓			✓			✓	✓	✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	○	○	BPJ																
a. Water Quality Controls Required (p. 218)			✓	✓		✓			✓	✓		✓	✓	✓	✓		✓		●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	○	○	BPJ																
b. Urban Payment-in-Lieu of On-Site Controls (p. 218)			✓	✓		✓			✓		✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	○	○	BPJ																
c. Water Quality Volume Capture (p. 219)			✓	✓		✓			✓	✓	✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	○	○	BPJ																
d. Water Quality Treatment Standards (p. 220)			✓			✓			✓	✓	✓	✓	✓	✓	✓		✓		●	●	●	●	●	●	●	●	●	●	●	BPJ	○	○	○	○	BPJ																

Masterplan Solutions - WPD Masterplan Update 2015/2016 (8/19/2016) - Inventory of Potential Solutions (12/15/2015)	Flood	Erosion	Water Quality	Integrated	Non-structural	Structural	Program Regulatory	Capital	Point	Line	Area	Public	Private	Partnership	Voluntary	Mandatory	City - Advisory	Development/regulatory	Permitting/enforcement	Pollution prevention	Strategic planning/mngmt	Education/outreach	Incentive /adoption	Awareness/ adoption	Probabilistic	Landuse-specific	Designers/engineers	Rural land owners	Programmatic	Co-benefits/spillover	Single Behavior	Repeated Behavior	Install and Maintenanc	Bacteria	Metals	Organics	Sediment	Pesticides	Nutrients	Oil and Grease	Dissolved Solids	Trash	Source	Peak Flow Reduction	Volume Reduction	Habitat Restoration /Creation	Aquatic Life	Source					
	Mission			Type	Method	Mode		Funding		Participation		Taylor/Fletcher 2007				Behavior Modification Category						Repeatability		Pollutants														Hydrologic Impact															
e. Water Quality Control Maintenance (p. 220)			✓	✓		✓		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓								✓			✓		✓		○	●	●	●	●	●	●	●	BPJ	○	○	○	●	BPJ						
70. Void and Water Flow Mitigation (p. 221)			✓	✓		✓		✓	✓	✓		✓	✓			✓	✓	✓	✓							✓	✓			✓		✓		○	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ						
71. Pollution Attenuation Plan (p. 221)			✓	✓		✓		✓			✓		✓				✓	✓	✓								✓			✓		✓		○	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ						
Integrated																																																					
X. Integrated Operating Programs (p.194)																																																					
72. Stormwater Control Maintenance (p. 194)			✓	✓		✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓		✓						✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	○	●	BPJ					
73. Drainage and Environmental Review (p. 195)			✓	✓		✓		✓	✓	✓		✓	✓			✓	✓	✓	✓			✓	✓	✓			✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	○	●	BPJ					
74. Drainage and Environmental Inspection (p. 195)			✓	✓		✓		✓	✓			✓	✓			✓	✓			✓	✓						✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ					
75. Value Engineering (p. 195)			✓	✓		✓		✓	✓	✓		✓	✓		✓		✓		✓	✓	✓	✓					✓	✓		✓	✓		✓	✓	○	○	○	○	○	○	○	○	BPJ	○	○	○	○	BPJ					
76. Watershed Master Planning (p. 196)			✓	✓		✓		✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓	✓			✓		✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
77. Data Management (p. 196)			✓	✓		✓		✓	✓	✓		✓	✓		✓		✓		✓		✓	✓			✓			✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ				
78. CIP Coordination (p. 197)			✓	✓		✓		✓	✓	✓		✓	✓		✓		✓	✓	✓		✓	✓					✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
79. Sustainability (p. 197)			✓	✓		✓		✓	✓	✓		✓	✓		✓		✓	✓		✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
XI. Integrated Regulations (p.221)																																																					
80. Imagine Austin Comprehensive Plan (p. 222)			✓	✓		✓		✓	✓	✓		✓	✓		✓	✓	✓	✓		✓	✓	✓		✓			✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
81. Impervious Cover Limits (p. 223)			✓	✓	✓		✓	✓		✓		✓	✓		✓		✓		✓								✓			✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
82. Impervious Cover Reductions via Development Regulations (p. 225)			✓	✓	✓		✓	✓		✓		✓	✓		✓		✓		✓								✓			✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
83. Flow Volume Limits (p. 226)			✓	✓		✓		✓				✓	✓			✓	✓	✓	✓									✓			✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	○	●	BPJ				
84. Disconnected Impervious Cover (p. 227)			✓	✓		✓			✓	✓		✓	✓		✓	✓	✓		✓		✓						✓			✓	✓		✓	✓	○	○	○	○	○	○	○	○	HDR - IC disconnect	○	○	○	○	HDR - IC disconnect					
85. Steep Slope Limits (p. 229)			✓	✓		✓		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓							✓	✓		✓	✓		✓	✓	○	○	○	○	○	○	○	○	BPJ	○	○	●	○	BPJ					
86. Stream Setbacks (p. 229)			✓	✓		✓		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓							✓	✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ				
87. Critical Environmental Features (CEF) Protection (p. 231)			✓	✓		✓		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓							✓	✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ				
88. Wetlands Protection (p. 232)			✓	✓		✓		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓							✓	✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ				
89. Landscape Regulations (p. 232)			✓	✓		✓		✓		✓		✓	✓			✓	✓	✓	✓	✓	✓	✓					✓	✓		✓	✓		✓	✓	○	○	○	○	○	○	○	○	BPJ	○	●	●	●	BPJ					
90. Tree Protection Standards (p. 234)			✓	✓		✓		✓				✓	✓			✓	✓	✓	✓	✓	✓	✓					✓	✓		✓	✓		✓	✓	○	○	○	○	○	○	○	○	BPJ	○		●	●	BPJ					
91. Natural Channel Conveyance (p. 235)			✓	✓		✓			✓			✓	✓			✓	✓	✓		✓	✓	✓											✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ					
XII. Incentives and Enforcement (p. 235)																																																					
92. Regulatory Incentives (p. 236)			✓	✓		✓		✓	✓	✓		✓			✓			✓	✓	✓	✓		✓				✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
93. Land Acquisitions and Conservation Easements (p. 236)			✓	✓		✓	✓		✓	✓		✓			✓		✓		✓	✓			✓				✓			✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
94. Variance Procedures (p. 237)			✓	✓		✓		✓	✓	✓			✓		✓		✓	✓	✓		✓						✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
95. Operations and Maintenance Permits for Water Quality Controls (p. 237)			✓	✓		✓	✓		✓				✓			✓		✓	✓								✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
96. Environmental Resource Inventory (p. 237)			✓	✓		✓	✓		✓	✓		✓	✓			✓	✓	✓									✓	✓		✓	✓		✓		●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ					
97. Payment-in-Lieu Alternatives (p. 238)			✓	✓		✓	✓		✓				✓		✓			✓	✓		✓						✓	✓		✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ					
98. Application of Standards to Single Residential Lot Construction on a Platted Lot (p. 239)			✓	✓		✓	✓		✓				✓			✓		✓	✓	✓						✓			✓	✓		✓	✓		●	●	●	●	●	●	●	●	BPJ	○	○	●	●	BPJ					
99. Application of Standards to Subdivision of Illegal Lots (p. 239)			✓	✓		✓	✓		✓				✓			✓		✓	✓						✓	✓		✓	✓		✓	✓		✓		●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ				
100. Redevelopment Exception Options (p. 239)			✓	✓		✓	✓		✓				✓					✓		✓	✓						✓			✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
101. Legal Enforcement (p. 240)			✓	✓		✓	✓		✓	✓	✓		✓			✓		✓	✓	✓	✓	✓					✓			✓	✓		✓	✓	●	●	●	●	●	●	●	●	BPJ	●	●	●	●	BPJ					
● - Modified from HDR based on BPJ																																																					
HDR - 2014 Nonstructural Non-Modeled Activity Pollutant Load Reduction Research - Appendix A - BMP chosent that is most like COA BMP																																																					
BPJ - Best Professional Judgement																																																					